Innovations in Environmental Engineering Education Programs

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Innovations in the Environmental and Ecological Engineering Undergraduate Education Program at Purdue University

Introduction

Engineering disciplines evolve over time, in response to ever-advancing theoretical understanding and the needs of society. The evolution of environmental engineering (EE) in the United States over the past 60 years is an excellent example of this process [1]-[3], as is the evolution of related disciplines such as sustainability science [4]. The Body of Knowledge for EE programs has expanded considerably [5], there has been substantial growth in the number of ABET accredited degree programs over the past 25 years (Fig. 1) [6], and in the number of students earning degrees in EE. Annually, in the United States, about 1,200 students earn ABET-accredited undergraduate degrees in EE, based on a survey of all accredited programs conducted in 2016 [7]. In 2014-2015, 1,124 bachelor’s degrees were awarded in the U.S., as reported by ASEE [8]. In addition, professional engineering licensure (NCEES) in the U.S. recognizes EE as a distinct professional discipline [9].

Fig. 1: Growth in ABET Accredited Undergraduate Environmental Engineering Programs 1966-2015 (data from [6]).

Given the changes in disciplinary knowledge, and the growth in educational programs and the number of practitioners, as well as evolving research challenges, there has been a call to transform the discipline of environmental engineering and science [10]. These authors call for and propose new paradigms, new practices, and new policies, as related to environmental engineering and science.
In this paper, we discuss the transformation of the EE undergraduate degree program at Purdue University. This program integrates a systems-based approach to studying anthropogenic impacts on the natural environment, helps to embed themes of environmental sustainability across different majors, and incorporates pedagogical innovation. In this paper, we discuss specific courses in the EE program that illustrate innovation of curriculum content. We also present data demonstrating undergraduate engineering student participation and interest in environmentally-related courses.

The impact of these education programs can be measured in terms of student participation in EE major programs, student diversity, and learning outcomes related to environmental sustainability.

Environmental and Engineering at Purdue University

The BS degree in Environmental and Ecological Engineering (EEE) received final approval from the Indiana Commission of Higher Education on September 14, 2012 and ABET accreditation in 2013, retroactive to October 2012. This marked the end of an almost decade-long process of program planning and launch.

The foundation of the EEE program was built through an NSF Curricular Planning grant awarded in 2002: “The Future Role of Ecological Engineering Science in Undergraduate Engineering Education.” The Purdue College of Engineering built on the work from this grant in 2004 with the creation of the “Environment in Engineering Committee,” an ad hoc committee charged with developing strategies to enhance research and educational programs related to the environment within the College of Engineering. The committee’s final report in 2005 recommended the creation of a new academic unit that could serve as a focal point within the college for environmental research and learning.

In 2007, EEE collaborated with the ABET-accredited Multidisciplinary Engineering (MDE) program at Purdue on the establishment of an EEE Plan of Study within MDE. One of the functions of the MDE program is to serve as an “incubator” for developing degree programs, allowing an immediate structure and home for students while a new program grows to critical mass and fully develops its courses. Though these early students were officially MDE students and met the MDE course requirements (which are slightly different from the current BSEEE requirements), they were taught, advised, and mentored by both EEE and MDE faculty and staff. The first three students entered the MDE/EEE plan of study in Fall 2008, and the first two graduated in December 2010. The program grew significantly to almost 50 students by Fall 2012.

Early in the planning process, the name of the proposed program was chosen to be “Environmental and Ecological Engineering,” rather than a more traditional “Environmental Engineering.” The name reflects unique aspects of the program and unique approaches relative to similar programs at peer institutions. We seek a broad systems perspective on addressing environmental issues, with a focus on ecological interactions and resilient designs that take into account complexity and connectivity between systems. In the undergraduate curriculum, this philosophy drives the early focus on systems thinking and systems understanding and leads to
the inclusion of significant course requirements in ecology, sustainability, and industrial ecology. These course requirements are in addition to those typically found in Environmental Engineering programs at peer institutions. A complete list of the program objectives, student outcomes and details about the EEE degree requirements are included in Appendix A.

Courses unique to the EEE program at Purdue, and representative of the overall philosophy include: “Environmental, Ecological, and Engineering Systems,” “Industrial Ecology and Life-Cycle Analysis,” and “Engineering Environmental Sustainability.” Courses that are common to most EE programs in the U.S. include “Introduction to Environmental and Ecological Engineering” and “Environmental and Ecological Engineering Senior Design.” In this paper, we will focus on the outcomes of synthesizing the unique disciplinary content of the program with courses that are more frequently offered in other programs.

After the BSEEE received final approval, students were transitioned out of the MDE program and into the EEE program. The first group of ten BSEEE students graduated in May 2013. Table 1 illustrates the growth in program enrollment and graduates of the ABET accredited program. It should be noted that Purdue has a common first year engineering (FYE) program; therefore, enrollment data are for sophomore – senior years only. Over the next five years, the EEE program is on track to achieve the planned capacity of 150 students.

Table 1: Five year growth in number of EEE undergraduate majors and degrees awarded.

<table>
<thead>
<tr>
<th>Academic Year</th>
<th>Enrollment</th>
<th>Fall Graduates</th>
<th>Spring Graduates</th>
<th>Summer Graduates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring 2013</td>
<td>51</td>
<td></td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>2013-14</td>
<td>62</td>
<td>2</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>2014-15</td>
<td>84</td>
<td>1</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>2015-16</td>
<td>95</td>
<td>7</td>
<td>15</td>
<td>2</td>
</tr>
<tr>
<td>2016-17</td>
<td>112</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: Spring 2013 was the first semester that students could enroll in EEE.
Student Diversity in the EEE major and courses

Approximately 10% of undergraduate EEE students are underrepresented racial minorities, 15% are international, and domestic students are split about equally between Indiana state residents and non-residents. Forty-five women and 38 men comprise the total number of BSEE graduates to date, and the percentage of female students (54%) mirrors that of nationwide graduates.

Recent national reports and literature have reported the affinity of female students towards specific engineering disciplines, including EE and similarly named programs. In the U.S., women earned 49.7% of the bachelor’s degrees in EE, which is the highest percentage for any discipline and higher than the overall percentage of women earning engineering degrees (19.9%) [8]. The relatively high proportion of women persists in advanced education in EE: women earn 39.6% of MS and 39.1% of PhD degrees in EE (data for 2014-2015) [8].

The pipeline of talent appears to be less “leaky” in EE. Higher participation rates for women in the EE degree programs seems to translate into higher participation rates for women in sustainable engineering leadership roles. For example, 39% of sustainability leadership positions in large design and construction firms are held by women, compared to 8% of general management positions [11]. Given the forecast growth in jobs in EE and related disciplines [12], the EE discipline will contribute substantially to the gender diversity of engineering overall.

Besides gender, there are other student characteristics that contribute to diverse perspectives in a major program and in classes. Several of the classes required for EEE majors also attract a wide disciplinary cross-section of students.
For example, over the period 2010-2017, “Introduction to Environmental and Ecological Engineering” enrolled students from over 50 programs or majors. The intellectual diversity is illustrated in Fig. 2. A large fraction of the students are comprised of Civil Engineering (CE), Chemical Engineering (ChE), Mechanical Engineering (ME) and EEE students. However, EEE is the only engineering major at Purdue that requires this class for graduation.

Fig. 2: Disciplinary diversity of students enrolled in the course: “Introduction to Environmental and Ecological Engineering” (2010-2017).
Another example is enrollment in “Engineering Environmental Sustainability.” This course also enrolled students from over 50 programs or majors. The disciplinary diversity is illustrated in Fig. 3, and is similar to that observed in Fig. 2. A larger fraction of the students are comprised of Electrical and Computer Engineering (ECE) students. This class is required for EEE majors, certain specialty areas in CE and multiple minors.

A final example is “Industrial Ecology and Life-Cycle Analysis.” To the best of our knowledge, EEE at Purdue is the only ABET accredited program in the U.S. that requires undergraduate students to complete a course and demonstrate proficiency in the area of life-cycle analysis. Although the course is dominated by students in the EEE major, a number of students from other programs enroll each term.
Fig. 4: Disciplinary diversity of students enrolled in the course “Industrial Ecology and Life Cycle-Analysis” (2012-2017).

The disciplinary diversity aligns with a national trend of broadly incorporating sustainability concepts into engineering curricula [13]. Courses with a wide spectrum of sustainable engineering content are being offered at U.S. universities. These three EEE courses, although required for graduation by only one or a few majors, are taken as elective courses by many students. The EEE program also offers a minor, and the three courses discussed here are requirements for the minor or often selected by students completing the minor. In addition, “Introduction to Environmental and Ecological Engineering” and “Engineering Environmental Sustainability” were part of a campus-wide curriculum transformation program, which also lent campus-wide visibility to the courses.

Assessment of Selected Student Outcomes

The EEE undergraduate degree is relatively new, with a small number of graduates. In this paper, we discuss qualitative assessments of selected student outcomes. The assessments are meant to be snapshots of student performance for a given year. We focus on assessing four EEE student outcomes (there are 13 total). Two of these outcomes are required by ABET for all engineering programs, and two are unique to EEE at Purdue. Each outcome is assessed by course instructors based on student performance on selected assignments or portions of assignments in required EEE courses. The assessment presented in this paper is not a comprehensive assessment of all outcomes, nor does it represent assessment by all stakeholders. Table 2 provides a brief description of the courses mapped to each outcome.
Assessed outcomes in this paper:

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.
d. An ability to function on multidisciplinary teams.
l. A knowledge of the roles and responsibilities of public institutions and private organizations pertaining to environmental and ecological engineering.
m. A knowledge of sustainability tools used in all engineering thought, and an ability to use these tools in the design process.

Table 2: Assessed student outcomes mapped to course descriptions.

<table>
<thead>
<tr>
<th>Course Title and Brief Description</th>
<th>Assessed Outcomes</th>
</tr>
</thead>
</table>
| *Introduction to Environmental and Ecological Engineering*  
Introduction to water pollution, air pollution, noise, hazardous and solid wastes, and their control. Environmental impact statements and global pollution issues. | d, l |
| *Engineering Environmental Sustainability*  
An introduction to the examination of global-scale resource utilization, food, energy and commodity production, population dynamics, and their ecosystem impacts. | d, m |
| *Environmental and Ecological Engineering Professional Practice Seminar*  
Seminar lectures and discussions to introduce students to aspects of professional practice within Environmental and Ecological Engineering. Topics include career planning and placement skills, professional responsibility and ethics, functioning as a professional, and other current important topics in the profession. Students will interact with several practicing Environmental and Ecological Engineers. | l |
| *Industrial Ecology and Life Cycle Analysis*  
The outputs and processes associated with industrial systems are examined, with special emphasis placed on interactions of these systems with environmental and ecological systems. A full product life cycle perspective is stressed, including energy and material flows, processes used to produce materials and realize products, and the management of end-of-life products | c, m |
| *Environmental and Ecological Engineering Senior Design*  
Senior-level environmental and ecological engineering design projects. Projects will integrate knowledge and skills learned earlier in the degree program and stress the application of the design process to interdisciplinary environmental and/or ecological engineering systems. | c |
Outcome c

Student performance in “Industrial Ecology and Life-Cycle Analysis” and “Environmental and Ecological Engineering Senior Design” serve as the basis for assessing outcome 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.”

Assessment from Industrial Ecology and Life-Cycle Analysis

After completing this course, students must demonstrate knowledge of life-cycle analysis (LCA), its different forms, its limitations, its endpoints, and the common tools, techniques and databases available to assist in LCA. Students demonstrate this by performing life cycle cost analysis to be able to better choose a design strategy from an economic perspective.

The assessment tool is shown below:

Assessment Tool: Question 3 on Final Exam

“A recent and continuing concern of automobile manufacturers is to improve fuel economy. One of the easiest ways to accomplish this is to make cars lighter. To do this, vehicle manufacturers have substituted specially strengthened – but lighter – aluminum for steel. Unfortunately processed aluminum is more expensive than steel about $3,000 per ton instead of $750 per ton for steel. Aluminum-intensive vehicles (AIVs) are expected to weigh less by replacing half of the steel in original car design with aluminum. For replacing, 0.8 ton of Aluminum is used per ton of replaced steel. This is expected to reduce fuel use by 20%.

Assume the fuel price to be same for all 5 years.

Assume the following:
- Current cars can travel 25 miles per gallon of gasoline and gasoline costs $3.50 per gallon.
- Current [steel] cars cost $20,000 to produce, of which $1,000 is currently for steel and $250 for aluminum.
- AIVs are equivalent to current cars except for substitution of lighter aluminum for steel.
- The life cycle of cars are 100,000 miles driven over 5 years which 20,000 miles per year.
- Discount rate is 5 % per year.

From a life cycle cost analysis would it make sense to make switch to AIVs?”

Scoring Rubric:
Excellent : 85-100 %; Acceptable: 70-85 % ; Marginal : 50-70 %; Unacceptable : Below 50 %.

Student Performance: Excellent 44 %; Acceptable 24 %; Marginal 27 %; Unacceptable 5 %, and over 90% of the students performed marginally or better on this outcome.
Assessment from Environmental and Ecological Engineering Senior Design

After students complete senior design, they should have an understanding of the complete design process and an ability to perform the process. Students demonstrate this by providing evidence of design skills and use the design process in the senior design final report, potentially including need-finding, brainstorming of alternatives, definition of criteria for evaluating alternatives, analysis, prototyping, and iteration. The specific assessment tool is shown below:

Assessment tool: Evaluation of final project reports, May 2016. Specifically looking for evidence of:

- need-finding or other description of the needs of the project
- clear description of design goals
- brainstorming or listing of various conceptual ideas to solve a problem
- criteria for decision, and analysis based on those criteria (decision matrix)
- iteration, perhaps following a prototype
- consideration of a variety of types of constraints

Scoring Rubric:

**Excellent:** (1) Project report shows clear design goals and clear evidence of consideration of the needs of stakeholders and users. (2) Multiple design solutions are considered, and a systematic method of evaluating the solutions and making a decision is clearly presented. (3) Project shows evidence of iteration of ideas, either after modeling, after experimentation, or after building of a prototype. (4) Project considers one or more of the following constraints: economic, environmental, social, political, ethical, health and safety, manufacturability, sustainability.

**Acceptable:** Project clearly demonstrates three of the four items listed above in “excellent.” Fourth item is implied in the report or its conclusions, but not directly addressed.

**Marginal:** Project likely meets most of the goals listed above for “excellent,” but project report does not fully demonstrate and document the goals. Instead, goal is implied through description of work or conclusions.

**Unacceptable:** Project report shows little or no use of a design process, and shows major deficiencies (or omissions) in more than one of the areas listed above for “excellent.”

Student Performance (evaluated by instructional team): Excellent 29%; Acceptable 57%; Marginal 14%; Unacceptable 0%, and 100% of the students performed marginally or better on this outcome.

Outcome d

Student performance in “Introduction to Environmental and Ecological Engineering” and “Engineering Environmental Sustainability” served as the basis for assessing outcome d: “An ability to function on multidisciplinary teams.”

Assessment from Introduction to Environmental and Ecological Engineering
After completing this course, students must demonstrate an ability to explain the principles of water, wastewater, air, soil, and hazardous waste treatment processes. They do this by working in teams during the semester to compare different pollution control technologies. This team project is 25% of the course grade. The teams were comprised of students from different majors and a balance of men and women. Students used Comprehensive Assessment of Team Member Effectiveness (CATME) system during team formation, mid-semester peer evaluations and final (end-of-semester) peer evaluations.

Students evaluated their peers in the following categories: 1) Contributing to Work, 2) Interacting with Teammates, 3) Keeping Team on Track, 4) Expecting Quality, 5) Having Knowledge/Skills, using a behaviorally anchored peer-evaluation scale. Each team member responded to a series of statements for the other members of their team (Fig. 5). Students rate their peers in all categories using the same scale, and different statements. Appendix B includes a complete listing of the categories and statements for each category.

![Fig. 5: Example screen of peer evaluation tool (CATME) utilized by students in “Introduction to Environmental and Ecological Engineering” (Fall 2016).](image)

Instructors are able to see individual student evaluations of each other, as well as aggregate evaluation, and aggregate evaluation corrected for the student’s self-evaluation. The CATME system calculates the aggregate evaluations (referred to as “Adjustment Factor” (AF) values) for each student. These adjustment factors are computed as the average rating of the student divided by the overall average rating for all members of the team. An adjustment factor value of 1 therefore means the student is contributing at the same level as the rest of the team. The student’s effort is less than average if the AF < 1, and greater than average if the AF > 1. The CATME system limits the maximum AF value to 1.05, and AF values > 0.95 are rounded to 1.

During the mid-semester peer evaluations, students demonstrated “An ability to function on multidisciplinary teams” as follows: Good: AF factor (w/o self) > 1.0 (47 students; 58%); Acceptable: AF factor (w/o self) = 1.0 (17 students; 21%); Marginal: AF factor (w/o self) > 0.9
and < 1.0 (5 students; 6.1%) Unacceptable: AF factor (w/o self) < 0.9 (12 students; 14.8%). Thus, 79% of the students demonstrated good or acceptable team function ability at the middle of the semester.

At the end of the semester, students completed the same CATME survey, and there was a slight increase in the number of the students were acceptable or good team members at the end of the semester (83%). The largest difference between the mid-semester and final evaluation is that the number of students with an unacceptable ability to function in multi-disciplinary teams decreased by 7.4% (from 14.8% to 7.4%).

Results of final peer evaluations: Good: AF factor (w/o self) > 1.0 (33 students; 41%); Acceptable: AF factor (w/o self) = 1.0 (34 students; 42%); Marginal: AF factor (w/o) self > 0.9 and < 1.0 (8 students; 9.9%); Unacceptable: AF factor (w/o self) < 0.9 (6 students; 7.4%). Over 90% of the students were marginal or better.

Assessment from Engineering Environmental Sustainability

Learning objectives of this course include: “students will learn how to be a productive team member, constructively evaluate their own and others’ performances, resolve conflicts effectively and encourage the willing contributions of everyone.” Team work products comprise 60% of the course grade.

In this course, there is an intentional team formation process, the students are in teams for the entire semester, the instructor provides mentoring specifically with regard to team function, and there is peer assessment of team function. The overall process is based on a rubric developed by the American Association of Colleges and Universities (AACU). See Appendix B for the full rubric.

Important attributes of the AACU rubric include that the instructor communicates expectations of team function, the team is responsible for managing contributions and conflict, and the instructor does not play an ‘enforcer’ role. These attributes are formalized with a written contract that describes expectations and a process for managing conflict, documentation of contributions and team communications, and three mandatory peer and self-evaluations. The teams are empowered to award or withhold credit for work products.

The evaluations consist of eight questions about the team that are based, in part, on the AACU teamwork rubric. These questions include:
1. What challenges are the team facing?
2. Who are the biggest contributors? Why are they so?
3. Who are the lesser contributors? Why are they so?
4. What actions will you take to improve the team?
5. Allocate 100 points based on Team Contribution to most recent work product.
6. Rate how each individual completes tasks on time, thoroughly and comprehensively, and whether they proactively help other team members.
Results for question 5, specifically for the lowest performing member of each team, are shown in Fig. 6.

![Fig. 6: Evaluation of lowest performing member in each team. Bars show value below team mean of lowest performing member (Spring 2016, n=105).](image)

Seven teams reported low performing members prior to mid-semester. These seven teams received active mentoring which included counseling on constructive engagement, and implementing an action plan for improved performance. Five of seven teams with low performing members were able to improve team function by the end of the semester. By the end of the semester, 16/20 teams functioned well: no team member was in the ‘region of concern.’

**Outcome 1**

Student performance in “Introduction to Environmental and Ecological Engineering” and “Environmental and Ecological Engineering Professional Practice Seminar” serve as the basis for assessing Outcome 1: “A knowledge of the roles and responsibilities of public institutions and private organizations pertaining to environmental and ecological engineering.”

*Assessment from Introduction to Environmental and Ecological Engineering*
After completing the course, students must demonstrate knowledge of major environmental legislation; identify legislation or components of legislation mandated reporting from common acronyms, and be able to briefly describe the goals and purpose of the legislations. The assessment tool is shown below:

Assessment tool: from final exam, Fall 2015, problem 1c and 1d.

Read the first 3 paragraphs of the article “Commercial Cooking Operations (Charbroiler) Registration.” Answer questions 1c and 1d with complete sentences.

**c. (25 points)** Identify the public institutions(s) and private organizations responsible for managing air quality, and explain each entity’s role.

**d. (10 points)** Identify the criteria pollutants that are being managed.

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**Commercial Cooking Operation (Charbroiler) Registration**

Charbroilers produce air pollutants such as volatile organic compounds (VOCs) and particulate matter (PM). VOCs react with other compounds in the atmosphere to form ground-level ozone, commonly called smog. Fine particles equal to or less than 10 microns in diameter, commonly referred to as PM10, pass through the ventilation system and are exhausted into the atmosphere.

Both VOC and PM10 present public health risks. Ozone produced from chemical reactions involving VOC may damage lung tissues and the respiratory tract. PM 10 can easily bypass the natural filters in the nose and throat and penetrate deep into the lungs and lead to wheezing, nose and throat irritation, bronchitis, aggravated asthma, and lung damage.

On December 5, 2007, the Board of Directors of the Bay Area Air Quality Management District adopted Regulation 6, Rule 2: Commercial Cooking Equipment. The new rule requires restaurants to install control devices for chain-driven and under-fired charbroilers in order to reduce the emission of particulates and in some cases, volatile organic compounds. All commercial cooking operations that are subject to the rule must also register their charbroiler(s) and control equipment with the BAAQMD and pay applicable fees.

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Scoring Rubric:

**Excellent:** All answers are complete and correct. Student demonstrates knowledge of all appropriate organizations and their role in managing air quality. All criteria pollutants being managed are correctly identified.

**Acceptable:** Most answers are complete and correct. Student shows partial misunderstanding of roles of institutions. At least one of two criteria pollutants is correctly identified.

**Marginal:** Student has no answer or is completely incorrect about most of the institutions. None of the criteria pollutants are identified.

**Unacceptable:** Student has no answer or is completely incorrect about the roles of the institutions. None of the criteria pollutants are identified.

Excellent: 18%; Acceptable: 82%; Marginal: 0%, Unacceptable: 0%, and 100% of students scored marginally or better.
Assessment from Environmental and Ecological Engineering Professional Practice Seminar

The course format is heavily based on external speakers who share their careers, insights, and comments on issues related to course objectives. One of the course objectives is to gain an understanding of major professional issues in EEE. Students demonstrate this by writing essays. The assessment tool from Spring 2016 is shown below:

Throughout the semester, you have been exposed to individuals from a variety of public and private organizations. Identify three speakers that come from organizations with dramatically different missions. For each of these organizations, discuss the roles and responsibilities of that organization as it relates to environmental and ecological engineering. Be specific and use examples from the speakers' presentations.

<table>
<thead>
<tr>
<th>Scoring Rubric</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Excellent:</strong> Student is able to identify three different types of organizations, and shows a clear understanding of the responsibilities of each type of organization, including the stakeholders that the organization must answer to.</td>
</tr>
<tr>
<td><strong>Acceptable:</strong> Student identifies three organizations and is able to describe their responsibilities, but does not explicitly list stakeholders, or does not have a wide variety of different types of roles and responsibilities.</td>
</tr>
<tr>
<td><strong>Marginal:</strong> Student discusses different organizations and their responsibilities, but does not show a clear understanding of how those organizations meet the responsibilities or how stakeholder groups are involved.</td>
</tr>
<tr>
<td><strong>Unacceptable:</strong> Little or no substantive reflection on roles and responsibilities; unable to identify three examples from speakers.</td>
</tr>
</tbody>
</table>

The students' essays are collected and evaluated using the above rubric. Excellent: 60%; Acceptable: 21%; Marginal: 19%; Unacceptable: 0%, and 100% of the students performed marginally or better on this outcome.

Outcome m

Outcome m: A knowledge of sustainability tools used in all engineering thought, and an ability to use these tools in the design process” is assessed based on student performance in “Engineering Environmental Sustainability” and “Industrial Ecology and Life Cycle Analysis.”

After completing “Engineering Environmental Sustainability” students will be able to evaluate conflicting information in the context of sustainability, ultimately increasing their information literacy and ability to produce scholarly products. Students demonstrate this by rationally assessing characteristics of information sources and logically evaluating their credibility. Students will be able to synthesize and information from diverse credible sources.
Scoring Rubric:

**Excellent**: The review demonstrates professional synthesis of research, information literacy skills and critical thinking ability. The article is thoroughly evaluated and integrated with other relevant content from the semester. All reference sources are high quality and listed in acceptable style.

**Acceptable**: The review demonstrates synthesis of research, information literacy skills and effort at critical thinking. The article is evaluated and integrated with other relevant content from the semester. Most reference sources are high quality and listed in acceptable style.

**Marginal**: The review demonstrates effort at synthesis of research, acceptable information literacy skills and marginal critical thinking. The article is incompletely evaluated and integration with other relevant content from the semester is minimal. Not all reference sources are good quality or listed in acceptable style.

**Unacceptable**: The review demonstrates little effort at synthesis of research, poor information literacy skills and no critical thinking. The article is incompletely evaluated and there is no integration with other relevant content from the semester. No reference sources are cited.

Student Performance: Excellent: 38%; Acceptable: 25%; Marginal: 20%; Unacceptable: 11%; Assignment not submitted: 7%, and over 80% of the students performed marginally or better.

**Assessment from Industrial Ecology and Life-Cycle Assessment**

Students must demonstrate knowledge of life-cycle analysis (LCA), its different forms, its limitations, its endpoints, and the common tools, techniques and databases available to assist in LCA and they do so by: a) Identification of appropriate Functional Unit and system boundary for the chosen LCA project b) Identify the relevant Life Cycle Inventory (LCI) and the Life Cycle Impact Assessment (LCIA) method for the goal of the project. c) Utilize both LCI and LCIA together to perform an impact assessment for the course project, thus demonstrate the knowledge of combining LCI to perform LCIA step of LCA and/or Use a hybrid approach by using EIO-LCA tool for course project d) Perform an appropriate interpretation analysis to suggest conclusions based on the project or lack thereof due to limitations of data available.
Assessment Tool: From Course Project Report that was provided required components for submission.
“Following Components must be included in your project Report:
   a. System Boundary explanation/Functional Unit Explanation.
   b. Data choice and quality of data information.
   c. Impact assessment results.
   d. Interpretation and discussion of limitations of your study.”

Scoring Rubric:

**Excellent:** The project report contains strong content for following a) Introduction to motivate the choice of product for LCA project b) Goal and scope that identifies the system boundary and type of LCA (Process/EIO/Hybrid) along with the main goal ie global warming, resource scarcity as the major focus of analysis c) Selection of data is based on reliable life cycle inventory that was introduced in class or based on published literature data. Data quality is assessed based on resource reliability. The data is collected as per project requirement and appropriate scaling performed for meeting the requirement of project and d) Interpretation stage should state the conclusions along with the limitations of the conclusion based on the project set-up.

**Acceptable:** The project report contains reasonable content for following a) Introduction to motivate the choice of product for LCA project b) Goal and scope that identifies the system boundary and type of LCA (Process/EIO/Hybrid) along with the main goal ie global warming, resource scarcity as the major focus of analysis c) Selection of data is based on reliable life cycle inventory that was introduced in class or based on published literature data. Data quality is assessed based on resource reliability. The data is collected as per project requirement and appropriate scaling performed for meeting the requirement of project and d) Interpretation stage should state the conclusions along with the limitations of the conclusion based on the project set-up. However, some of the sections need more work in terms of explanation and calculations.

**Marginal:** The project report has all the sections properly represented however lacks in at-least two LCA steps in terms of contents and methodological aspects.

**Unacceptable:** The project demonstrates weaknesses in the selection of system boundary for project, the selection of life cycle inventory is not appropriate and the LCIA calculation is incomplete. The limitations of the study is not well represented in terms of interpretation and conclusions. Overall, the LCA methodology application is weak.

Student Performance: Excellent: 32 %; Acceptable: 35 %; Marginal: 33 %; Unacceptable: 0 %, and 100 % of students achieved marginal or better.
The assessed student outcomes presented here are one measure of the success of meshing the current EE paradigms with newer paradigms. As previously mentioned, the EEE undergraduate program includes an early focus on systems thinking and systems understanding and leads to unique course requirements in ecology, sustainability, and industrial ecology. The course utilized in the assessment study here represent a spectrum of content and philosophy that spans paradigms, including traditional EE paradigms as well as newer ones. The courses “Engineering Environmental Sustainability” and “Industrial Ecology and Life-Cycle Analysis” emphasize newer paradigms, and the course “Introduction to Environmental and Ecological Engineering” focuses on the more traditional paradigm of environmental controls. Courses such as “Environmental and Ecological Senior Design” and “Environmental and Ecological Professional Practice” attempt to synthesize the various paradigms in a single course for upper division students. For almost all outcomes assessed, over 90% of the students were marginally proficient or better, and this is one indication that the program is successfully integrating traditional and evolving paradigms, and thus moving towards a transformation of the discipline.

The ultimate purpose for gathering outcome assessment data is to inform the program’s continuous improvement effort. While outcomes assessments are a key component of the continuous improvement process, they are integrated in a structured process with other information. Instructors of EEE courses complete a self-evaluation at the conclusion of each semester. Instructors synthesize their own observations, results from student evaluations, input from teaching assistants and outcomes assessment data to reflect on what went well, and most importantly, plan for what actions will be taken to improve the course the next time it is taught.

The EEE program meets with an external advisory council (EAC) comprised of professionals working in the discipline, two times each year. The topics discussed with the EAC rotate, but include EEE program objectives and outcomes, course development as well as knowledge and skills needed in the workforce. FE exams results, staff reports and senior exit surveys provide additional data for the continuous improvement process. The EEE Academics Committee is responsible for collecting, reviewing and summarizing the program’s data, and reporting to the EEE faculty. Every spring, at the conclusion of the academic year, the EEE faculty convene for an all day workshop devoted to program improvement. The EEE program is relatively new, and there is an emphasis on using the continuous improvement data to make ongoing enhancements to course content and pedagogy.

Graduates of this program find employment with traditional environmental engineering employers such as consulting firms and environmental compliance in large industry, but new opportunities have emerged in energy financing, entertainment/tourism and multinational professional services. Many companies are now hiring BSEEE students and placing them in “Sustainable Engineering” assignments rather than traditional environmental engineering work. Employers have commented that EEE students take a systems approach to address environmental issues that allows the problem to be addressed further “upstream.” It was noted that EEE graduates work on preventing problems before they happen instead of fixing the problems after they happen. The availability of employment in the new space of “Industrial Sustainability” is helping to attract students with more diverse interests.
References


7. Margaret Busse, Purdue University-West Lafayette, personal communication.


Acknowledgements
The authors provided assessment data from their own courses, and also thank the following faculty for providing assessment data: John Howarter, John Sutherland, Shweta Singh.
Appendices

Appendix A: Educational Objectives, Student Outcomes, and Degree Requirements and sample Plan of Study for the BSEEE at Purdue University.

Program Educational Objectives
Graduates of the EEE Undergraduate Program will:
Be prepared to assume immediate employment in the fields of environmental and ecological engineering or to continue education in an advanced degree program;
Participate fully and ethically in the advancement of the profession within five years of graduation, as measured by one or more of the following:
  a. Achievement of, or significant progress toward, professional licensure
  b. Achievement of, or significant progress toward, an advanced degree
  c. Publication of research results and/or field reports
  d. Advancement to leadership roles within an engineering organization
  e. Professional participation in international engineering activities
  f. Participation with organizations, agencies, or companies who offer solutions to major societal and environmental issues.

Student Outcomes
Upon Graduation, Graduates of EEE will Show:
  a. An ability to apply knowledge of mathematics, science, and engineering
  b. An ability to design and conduct experiments, as well as to analyze and interpret data
  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
  d. An ability to function on multidisciplinary team
  e. An ability to identify, formulate, and solve engineering problem
  f. An understanding of professional and ethical responsibility
  g. An ability to communicate effectively
  h. The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
  i. A recognition of the need for, and an ability to engage in life-long learning
  j. A knowledge of contemporary issues
  k. An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice
  l. A knowledge of the roles and responsibilities of public institutions and private organizations pertaining to environmental and ecological engineering
  m. A knowledge of sustainability tools used in all engineering thought, and an ability to use these tools in the design process.
Degree Requirements (128 credits)

Departmental/Program Major Courses (46 credits)

Required Major Courses (23 credits)

(3) Environmental, Ecological, and Engineering Systems
(1) Introduction to Environmental and Ecological Engineering Seminar
(3) Environmental and Ecological Systems Modeling
(3) Introduction to Environmental And Ecological Engineering
(3) Engineering Environmental Sustainability
(3) Environmental and Ecological Engineering Laboratory
(1) Environmental and Ecological Engineering Professional Practice Seminar
(3) Industrial Ecology And Life Cycle Analysis
(1) Environmental and Ecological Engineering Senior Design
(2) Environmental and Ecological Engineering Senior Design

EEE Selectives (18cr) & Technical Electives (5cr)

(3) EEE Selective I - Column A
(3) EEE Selective II - Column B
(3) EEE Selective III - Column C
(3) EEE Selective IV
(3) EEE Selective V
(3) EEE Selective VI
(2) Technical Elective I
(3) Technical Elective II

Other Departmental/Program Course Requirements (55 credits)

(2) * Transforming Ideas to Innovation I
(2) * Transforming Ideas to Innovation II
(4) *MA 16500 Analytic Geometry & Calculus I
(4) *MA 16600 Analytic Geometry & Calculus II
(4) *CHM 11500 General Chemistry I
(4) *CHM 11600 General Chemistry II
(4) *PHYS 17200 Modern Mechanics
(4) MA 26100 Multivariate Calculus
(4) MA 26200 Linear Algebra and Differential Equations
(3) CE 29700 Basic Mechanics I (Statics)
(3) CE 29800 Basic Mechanics II (Dynamics)
(2) BIOL 12100 Biology I: Diversity, Ecology, and Behavior
(3/1) CE 34000 Hydraulics + CE 34300 Hydraulics Laboratory
(3) STAT 35000 Introduction to Statistics
(2) BIOL 28600 Intro. Ecol. & Evolution
(3) BIOL 58500 Ecology

EEE General Education Electives (24 credits) and Free Elective (2-3 credits)

(*Satisfies First Year Engineering)
### Sample Plan of Study (Sophomore to Senior Year)

<table>
<thead>
<tr>
<th>Credits</th>
<th>Fall of second year</th>
<th>Credits</th>
<th>Spring of second year</th>
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<td>Environmental, Ecological, and Engineering Systems</td>
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<td>Introduction to Environmental And Ecological Engineering</td>
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<td>Linear Algebra and Differential Equations</td>
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<td>Engineering Environmental Sustainability</td>
<td>3</td>
<td>Basic Mechanics I (Statics)</td>
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<td>Biology I: Diversity, Ecology, and Behavior</td>
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<td>Thermodynamics I</td>
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<td>Multivariate Calculus</td>
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<td>3</td>
<td>Environmental and Ecological Engineering Laboratory</td>
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<tr>
<td>3</td>
<td>Basic Mechanics II (Dynamics)</td>
</tr>
<tr>
<td>3</td>
<td>Introduction to Statistics</td>
</tr>
<tr>
<td>2</td>
<td>Technical Elective I</td>
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<td>3</td>
<td>EEE Selective I - Column A</td>
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<tr>
<td>3</td>
<td>General Education Elective</td>
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<table>
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<th>Fall of fourth year</th>
<th>Spring of fourth year</th>
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<td>1</td>
<td>Environmental and Ecological Engineering Senior Design</td>
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<td>2</td>
<td>Environmental and Ecological Engineering Senior Design</td>
</tr>
<tr>
<td>3</td>
<td>EEE Selective III – Column C</td>
</tr>
<tr>
<td>3</td>
<td>EEE Selective IV</td>
</tr>
<tr>
<td>3</td>
<td>Ecology</td>
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<td>3</td>
<td>General Education Elective</td>
</tr>
<tr>
<td>3</td>
<td>Technical Elective II</td>
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This plan of study includes and highlights all of the EEE program specific courses.
Appendix B: CATME Peer Evaluation Categories, Statements, Scale and AACU team work value rubric

CATME Peer Evaluation Categories, Statements, and Scale

**Contributing to the Team’s Work**

- Does more or higher-quality work than expected.
- Makes important contributions that improve the team's work.
- Helps teammates who are having difficulty completing their work.

Demonstrates behaviors described immediately above and below.

1. Completes a fair share of the team's work with acceptable quality.
2. Keeps commitments and completes assignments on time.
3. Helps teammates who are having difficulty when it is easy or important.

Demonstrates behaviors described immediately above and below.

4. Does not do a fair share of the team's work. Delivers sloppy or incomplete work.
5. Misses deadlines. Is late, unprepared, or absent for team meetings.
6. Does not assist teammates.
7. Quits if the work becomes difficult.

**Interacting with Teammates**

- Asks for and shows an interest in teammates' ideas and contributions.
- Makes sure teammates stay informed and understand each other.
- Provides encouragement or enthusiasm to the team.
- Asks teammates for feedback and uses their suggestions to improve.

Demonstrates behaviors described immediately above and below.

- Listens to teammates and respects their contributions.
- Communicates clearly. Shares information with teammates.
- Participates fully in team activities.
- Respects and responds to feedback from teammates.

Demonstrates behaviors described immediately above and below.

- Interrupts, ignores, bosses, or makes fun of teammates.
- Takes actions that affect teammates without their input. Does not share information.
- Complains, makes excuses, or does not interact with teammates
- Is defensive. Will not accept help or advice from teammates.
Keeping the Team on Track

- Watches conditions affecting the team and monitors the team's progress.
- Makes sure that teammates are making appropriate progress.
- Gives teammates specific, timely, and constructive feedback.

Demonstrates behaviors described immediately above and below.

- Notices changes that influence the team's success.
- Knows what everyone on the team should be doing and notices problems.
- Alerts teammates or suggests solutions when the team's success is threatened.

Demonstrates behaviors described immediately above and below.

- Is unaware of whether the team is meeting its goals.
- Does not pay attention to teammates' progress.
- Avoids discussing team problems, even when they are obvious.

Having Related Knowledge, Skills, and Abilities

- Demonstrates the knowledge, skills, and abilities to do excellent work.
- Acquires new knowledge or skills to improve the team's performance.
- Able to perform the role of any team member if necessary.

Demonstrates behaviors described immediately above and below.

- Demonstrates sufficient knowledge, skills, and abilities to contribute to the team's work.
- Acquires knowledge or skills as needed to meet requirements.
- Able to perform some of the tasks normally done by other team members.

Demonstrates behaviors described immediately above and below.

- Missing basic qualifications needed to be a member of the team.
- Unable or unwilling to develop knowledge or skills to contribute to the team.
- Unable to perform any of the duties of other team members.
<table>
<thead>
<tr>
<th>Expecting Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Motivates the team to do excellent work.</td>
</tr>
<tr>
<td>• Cares that the team does outstanding work, even if there is no additional reward.</td>
</tr>
<tr>
<td>• Believes that the team can do excellent work.</td>
</tr>
</tbody>
</table>

Demonstrates behaviors described immediately above and below.

| • Encourages the team to do good work that meets all requirements.  |
| • Wants the team to perform well enough to earn all available rewards.  |
| • Believes that the team can fully meet its responsibilities.  |

Demonstrates behaviors described immediately above and below.

| • Satisfied even if the team does not meet assigned standards.  |
| • Wants the team to avoid work, even if it hurts the team.  |
| • Doubts that the team can meet its requirements.  |
The VALUE rubrics were developed by teams of faculty experts representing colleges and universities across the United States through a process that examined many existing campus rubrics and related documents for each learning outcome and incorporated additional feedback from faculty. The rubrics articulate fundamental criteria for each learning outcome, with performance descriptors demonstrating progressively more sophisticated levels of attainment. The rubrics are intended for institutional-level use in evaluating and discussing student learning, not for grading. The core expectations articulated in all 15 of the VALUE rubrics can and should be translated into the language of individual campuses, disciplines, and even courses. The utility of the VALUE rubrics is to position learning at all undergraduate levels within a basic framework of expectations such that evidence of learning can be shared nationally through a common dialog and understanding of student success.

**Definition**

Teamwork is behaviors under the control of individual team members (effort they put into team tasks, their manner of interacting with others on team, and the quantity and quality of contributions they make to team discussions.)

**Framing Language**

Students participate on many different teams, in many different settings. For example, a given student may work on separate teams to complete a lab assignment, give an oral presentation, or complete a community service project. Furthermore, the people the student works with are likely to be different in each of these different teams. As a result, it is assumed that a work sample or collection of work that demonstrates a student's teamwork skills could include a diverse range of inputs. This rubric is designed to function across all of these different settings.

Two characteristics define the ways in which this rubric is to be used. First, the rubric is meant to assess the teamwork of an individual student, not the team as a whole. Therefore, it is possible for a student to receive high ratings, even if the team as a whole is rather flawed. Similarly, a student could receive low ratings, even if the team as a whole works fairly well. Second, this rubric is designed to measure the quality of a **process**, rather than the quality of an **end product**. As a result, work samples or collections of work will need to include some evidence of the individual's interactions within the team. The final product of the team's work (e.g., a written lab report) is insufficient, as it does not provide insight into the functioning of the team.

It is recommended that work samples or collections of work for this outcome come from one (or more) of the following three sources: (1) students' own reflections about their contribution to a team's functioning; (2) evaluation or feedback from fellow team members about students' contribution to the team's functioning; or (3) the evaluation of an outside observer regarding students' contributions to a team's functioning. These three sources differ considerably in the resource demands they place on an institution. It is recommended that institutions using this rubric consider carefully the resources they are able to allocate to the assessment of teamwork and choose a means of compiling work samples or collections of work that best suits their priorities, needs, and abilities.
**Teamwork VALUE Rubric**

**Definition**

Teamwork is behaviors under the control of individual team members (effort they put into team tasks, their manner of interacting with others on team, and the quantity and quality of contributions they make to team discussions.)

Evaluators are encouraged to assign a zero to any work sample or collection of work that does not meet benchmark (cell one) level performance.

<table>
<thead>
<tr>
<th>Teamwork VALUE</th>
<th>Capstone 4</th>
<th>Milestones 3</th>
<th>Benchmark 1</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Contributes to Team Meetings</strong></td>
<td>Helps the team move forward by articulating the merits of alternative ideas or proposals.</td>
<td>Offers alternative solutions or courses of action that build on the ideas of others.</td>
<td>Shares ideas but does not advance the work of the group.</td>
</tr>
<tr>
<td><strong>Facilitates the Contributions of Team Members</strong></td>
<td>Engages team members in ways that facilitate their contributions to meetings by both constructively building upon or synthesizing the contributions of others as well as noticing when someone is not participating and inviting them to engage.</td>
<td>Engages team members in ways that facilitate their contributions to meetings by restating the views of other team members and/or asking questions for clarification.</td>
<td>Engages team members by taking turns and listening to others without interrupting.</td>
</tr>
<tr>
<td><strong>Individual Contributions Outside of Team Meetings</strong></td>
<td>Completes all assigned tasks by deadline; work accomplished is thorough, comprehensive, and advances the project. Proactively helps other team members complete their assigned tasks to a similar level of excellence.</td>
<td>Completes all assigned tasks by deadline; work accomplished is thorough, comprehensive, and advances the project.</td>
<td>Completes all assigned tasks by deadline.</td>
</tr>
<tr>
<td><strong>Fosters Constructive Team Climate</strong></td>
<td>Supports a constructive team climate by doing all of the following: • Treats team members respectfully by being polite and constructive in communication. • Uses positive vocal or written tone, facial expressions, and/or body language to convey a positive attitude about the team and its work. • Motivates teammates by expressing confidence about the importance of the task and the team's ability to accomplish it. • Provides assistance and/or encouragement to team members.</td>
<td>Supports a constructive team climate by doing any three of the following: • Treats team members respectfully by being polite and constructive in communication. • Uses positive vocal or written tone, facial expressions, and/or body language to convey a positive attitude about the team and its work. • Motivates teammates by expressing confidence about the importance of the task and the team's ability to accomplish it. • Provides assistance and/or encouragement to team members.</td>
<td>Supports a constructive team climate by doing any one of the following: • Treats team members respectfully by being polite and constructive in communication. • Uses positive vocal or written tone, facial expressions, and/or body language to convey a positive attitude about the team and its work. • Motivates teammates by expressing confidence about the importance of the task and the team's ability to accomplish it. • Provides assistance and/or encouragement to team members.</td>
</tr>
<tr>
<td><strong>Responds to Conflict</strong></td>
<td>Addresses destructive conflict directly and constructively, helping to manage/resolve it in a way that strengthens overall team cohesiveness and future effectiveness.</td>
<td>Identifies and acknowledges conflict and stays engaged with it.</td>
<td>Passively accepts alternate viewpoints/ideas/opinions.</td>
</tr>
</tbody>
</table>