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Environmental and Ecological Engineering in Context: A Foundational Graduate Course

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Introduction

Many contemporary global challenges are dependent on maintaining environmental quality, and this motivates professional training and higher educational degree program development. In the United States (U.S.), the number of ABET accredited environmental engineering undergraduate degree programs and student enrollments have grown substantially over the past 30 years. These students are part of the pipeline into graduate degree programs. In the U.S., during the 2017-2018 academic year, 2805 masters degrees were awarded in Civil/Environmental or Environmental Engineering (EE), and 457 doctoral degrees were awarded (*1*). Over the decades, there has been discussion about needs, challenges and assessment related to environmental engineering graduate programs (*2-4*), and development of an accepted Body of Knowledge for Environmental Engineering (*5,6*). The challenges include graduate student cohorts that are comprised of students whose undergraduate training is drawn from a variety of engineering and natural science disciplines. This is in contrast to many other engineering graduate programs, whose graduate students are comprised primarily of students who earned an undergraduate degree in the same degree area.

More broadly, there have been discussions about enhancing graduate education in STEM disciplines (*7*). While graduate school emphasizes more specialized study in a discipline, there is a need for balancing depth and breadth in terms of knowledge and skills. In addition, it is important that all graduates of an EE program have a common intellectual foundation. Graduate level courses also serve as a bridge between "education" and "research," and an important aspect of graduate education is training students to do research and advance the forefront of knowledge in EE.

At Purdue University, West Lafayette, IN, a graduate program in Environmental and Ecological Engineering (EEE), conferring both Masters and Doctoral degrees, was launched in 2015. The program is organizationally and intellectually unique. The administrative structure is such that all core faculty in EEE hold joint appointments in other engineering departments, including Agriculture and Biological Engineering, Civil Engineering, Industrial Engineering, Materials Engineering, and Mechanical Engineering. In addition, some EEE faculty hold joint appointments in the sciences, including Agronomy or Forestry and Natural Resources. Currently, there are 16 core EEE faculty. These core faculty teach graduate level courses in EEE, oversee EEE research projects, and mentor EEE graduate students. This structure offers the important advantage of breadth of knowledge and perspective, which supports the availability of a variety of research topics and courses to the graduate student population. The program learning objectives are included in Appendix A, and are based on accepted Body of Knowledge documents. The faculty of EEE viewed the launch period as an opportunity to innovate the graduate program culture and pedagogical methods.

The knowledge dimension motivates pedagogical methods. Many engineering challenges, including most environmental challenges, are "wicked problems." Wicked problems are exactly the opposite of tame problems, which are clearly defined, and a direct scientific approach will lead to a single correct solution. In contrast, there is often no consensus about a definition or scope of a wicked problem. Wicked problems exist in a dynamic knot of social, policy, economic, moral, ethical and technical dimensions. Attempts to solve wicked problems frequently yield unintended outcomes that render the solution unsatisfactory or incomplete. Environmental engineering practice addresses challenges more like wicked problems than tame problems. Accordingly, teaching principles of environmental engineering "in context" of the real social, political, economic and technical dimensions that exist with the challenges professionals face in practice provides students with an opportunity to develop critical thinking skills necessary to be successful in their careers. Assessment of teaching in-context, and examples from different STEM disciplines, are described in (*8-9*). This paper describes the origin, implementation and assessment of a foundational graduate course, developed with the premise of teaching graduate students how to approach wicked problems, and describes how the course fits within the rest of the graduate program requirements.

Launch of the EEE Graduate Program

Graduate study emphasizes specialization in the discipline, and advancing the forefront of knowledge through research. With regards to many EEE graduate programs, a challenge to immediate specialization is that incoming students exhibit a wide range of preparation (undergraduate major, or most recent prior degree). This is in contrast to other engineering disciplines, whose incoming graduate students have a much more standard preparation: an undergraduate degree in the same major as the graduate program.

In addition, students whose undergraduate major is different than EEE may lack knowledge about EEE-specific research areas and methods. For graduate students who wish to complete research (MS thesis or Doctoral dissertation), it is important to be familiar with the research expertise and advising styles of all faculty as soon as possible after entry into the program.

An analysis of the currently enrolled graduate students in EEE at Purdue University yields Table 1. Notably, the percentage of students who earned a degree in EEE is a minority (28%) of the total. Approximately two-thirds of the students earned a degree in any engineering field. The number of students who have degrees in environmental science (13%) is comparable to the number who studied other natural sciences (11.3%). The remaining students hold degrees in areas such as Public Policy or Management.

Table 1: Disciplinary Breadth of Graduate Students at Purdue University

Most recent prior major	% of enrolled graduate students
Environmental and Ecological Engineering (EEE)*	28%
Engineering, non-EEE	39.6%
Environmental Science (ES)	13%
Natural Science, non-ES	11.3%

Other (includes Public Policy, Management)	5.6%

*An aggregation of engineering program names that include the word "Environmental" ("Civil and Environmental Engineering" or "Environmental Engineering," etc).

Some of the more specialized graduate courses that are at the foundation of graduate study in EEE, already existed at Purdue University. Examples include a graduate level course in aquatic chemistry for environmental engineers, which had been taught for many years before the launch of the EEE graduate program. In order to meet the programmatic learning objectives, and develop a curricula that was aligned with the accepted Body of Knowledge, the faculty agreed that additional courses would need to be developed, including a foundational course required for all students.

During an EEE faculty retreat in May 2015, the faculty converged on a plan to leverage collaborative teaching to launch the EEE graduate program. The faculty agreed on two important foundations: a core topics list (which included input and ranking by all faculty at the retreat), and a structure for a foundational graduate course. The core topics list is included as Appendix B. In order to catalyze the effort, maximize initial impact, and distribute the invested time widely across EEE faculty, a collaborative teaching model was agreed upon. Collectively, the faculty would teach six 1-credit modules in series; three starting in Spring 2016 and three in Fall 2016. Each 1-credit module (five weeks) was led by two EEE faculty with complementary (not overlapping) research expertise. These modules would be required for all graduate students, and be completed during the first year of graduate study by most students.

There are three overarching objectives of the six-module sequence. First, every EEE graduate student will be exposed to a broad foundation of fundamental principles that will allow students to explore and expand their knowledge beyond their primary interests. Second, every EEE faculty member will have the opportunity to teach in their areas of primary interest and substantively interact with all incoming EEE students. Finally, the modules will help build a cohort and community of students with a shared experience and common background. These objectives directly address some of the challenges of graduate education in EEE and related fields.

The core topics (fundamental principles) of EEE were taught in-context with "Case Stories." Each Case Story was built around contemporary issues, and included for example, history, regulations, interconnectedness, applications, processes and products. Weaving a cloth is a metaphor for this approach. At one end are the core topics (Appendix B) and at the other end are the program learning outcomes (Appendix A). The curriculum is the fabric that is woven to connect the core topics to the learning outcomes. Module instructors chose a Case Story to provide the context for the module, identified core topics (about five) to be covered, and mapped core topics to the learning outcomes. Table 2 shows course titles for every module that has been offered through Fall 2019. All core faculty were instructors for the modules listed below at least once, and often multiple times. Approximately 80 EEE graduate students have completed the modules.

Table 2: Course Titles (Case Stories) for EEE modules

Semester/Year	Course Title (Case Story)
Spring 2016	Direct Potabilization
Spring 2016	Recovering Value from Solid Waste: Biological and Chemical Approaches
Spring 2016	Discovering Green Chemistry
Fall 2016	The Internet of Sustainability
Fall 2016	Data Analytics for Energy
Fall 2016	Modeling Complexity
Spring 2017	Direct Potabilization
Spring 2017	Recovering Value from Solid Waste: Biological and Chemical Approaches
Spring 2017	Deconstructing a Garbage Gyre
Fall 2017	The Internet of Sustainability
Fall 2017	Environmental Impact in Automotive Systems
Fall 2017	Modeling Complexity
Spring 2018	Data Analytics for Energy
Spring 2018	Recovering Value from Solid Waste: Biological and Chemical Approaches
Spring 2018	Coastal Resilience Engineering
Fall 2018	Introduction to Environmental Photochemistry
Fall 2018	Environmental Engineering Ethics and Society
Fall 2018	Membranes For Water Treatment
Spring 2019	Photoreactors: Theory And Applications
Spring 2019	Modeling Complex Industrial Systems
Spring 2019	Analysis Of Water Contaminants
Fall 2019	Life Cycle of Plastics
Fall 2019	Design of Sustainable Plastics
Fall 2019	Plastics Recycled and End of Life

The modules serve the needs of students with diverse undergraduate preparation and graduate degree objective. Students may earn PhD degrees, and various types of MS degrees, including an MS (non-thesis), MS (thesis), and Professional Masters. With such disciplinary diversity, it is important that students have a common foundation before completing more specialized graduate courses. Table 3 demonstrates that the module course structure provides balance between breadth and depth. The required modules are 6 credits. Therefore, after the completing the modules, students still have a significant number of credits left for completing more specialized courses.

Table 3: Degree type and required credits for coursework and research

Degree	Course Credits	Research Credits
PhD	48	42
MS, thesis	21	9
MS, non-thesis and Professional Masters	30	0

Detailed Case Study of a Module

To gain insight into the module structure, a more detailed description and analysis of selected modules will be presented. One module has been offered three times: "Recovering Value from Solid Waste: Biological and Chemical Approaches" and will be described more fully in terms of content and pedagogy. This course was team taught by two faculty: Professor Michael Mashtare, who contributed expertise in microbiology and soil systems, and Professor Inez Hua, who contributed expertise in environmental chemistry and pollution control. This case story was chosen because the economic and functional values residing in solid 'wastes' are often overlooked, and because the subject provides good connection between core topics and learning outcomes. Students integrated life-cycle thinking with fundamental science (biology and chemistry) to explore or develop approaches for the enhanced recovery of value from solid waste. The five week course was centered on a term project, completed in teams, and the communication mode of each team's finding was unique.

This case story encompassed the following learning outcomes and core topics:

Learning Outcomes
Outcome 1: Basic Environmental Math and Science
Outcome 5: Problem Formulation and Analysis
Outcome 6: Design
Outcome 9: Globalization and other Contemporary Issues
Outcome 12: Effective Communication

Core Topics:
Environmental biological processes
Environmental chemistry
Multi-criteria decision making
Remanufacturing, recycling and End-of-Life
Solid waste and hazardous waste

Full descriptions of the learning outcomes are available in Appendix A.

The ten course periods of the module included a mix of faculty lecture, student discussion of research articles and case studies, and intensive work on a term project. Major elements of the course were directed to help students with the term project. Teams of students were assigned to formulate a contemporary problem related to solid residuals by considering the life cycle of engineered products, then compare alternative solutions, select an optimal solution using a weighted sum method (a simple version of multi-criteria decision analysis), and communicate the results to a broad audience. The solutions needed to be based on biological and/or chemical processes. Students formulated their problems based on a view of global economic sectors, rather than just the U.S. and the fact that manufacturing supply chains are often global.

From the 2018 student cohort, five project titles emerged: "Bones to Biodiesel, Waste Recovery from Cattle Bone By-Product"; "Recovering Energy from Natural Casings Processing Waste"; "Recovery from Spent Alkaline Batteries: Biohydrometallurgical Processes"; "Scale it Up: Evaluating Different Disposal Methods for Fish Scale Waste"; and "Potato Waste to Bioplastics."

Student deliverables included an abstract, technical summary and final presentation. The format of the final presentation varied. During 2017, students produced a video that was viewed and discussed by various stakeholders. During 2016 and 2018, students made final presentations to a local community audience at an event called Science on Tap. Science on Tap events are in the same category as Science Cafes, and are locally organized across the United States. These events are at public venues such as libraries, cafes, and pubs, and involve a scientific expert speaking about a specific topic with members of the community. Rather than presenting in the classroom, to an audience of specialists, students were able to interact and explain their findings at an event that attracted several hundred participants. More information about the Science on Tap format is available (*10*).

Evaluation and Continuous Improvement

The modules were assessed using focus groups and surveying. In April 2016 and 2017 focused groups collected feedback from students participating in the modules (n=14 and n=16, respectively). Additionally, the EEE faculty completed an online, open-ended survey in February of 2017 (n=12). Most recently, in November 2019, twenty students completed an online, open-ended survey focused upon the effectiveness of team teaching and the integration of a theme tying all modules together. Results from the April 2016 and 2017 student focus groups, as well as the February 2017 faculty survey were presented at two EEE faculty retreats in May 2016 and May 2017.

Student Focus Groups Findings

The focus group interviews were semi-structured and organized to investigate the following categories: expectations, organization and structure, curricular content, and instructional strategies. Data from the focus groups was qualitatively coded for emergent categories. Based upon the student feedback, the following recommendations and example excerpts used for coding were provided at the May 2016 and 2017 faculty retreats (Table 4).

Table 4: May 2016 and 2017 faculty recommendations based upon student focus group feedback.

	May 2016 Recommendations	May 2017 Recommendations
Category of Investigation: Expectations		
Construct	Clarify expectations for modules	Continued focus on intentions and expectations, i.e., introduce faculty and research; deliver appropriate workloads across semester
Example Excerpts	"Clear expectations for what LOs are supposed to be for modules in general—is this introductory, supplemental, shared experience, foundational, gateway experience" "Naming of the 'seminar' is inaccurate"	"Share their research and research group—beyond just sharing their areas of work 1st day"
Category of Investigation: Organization & Structure		
Construct	Develop clear learning outcomes; allow for 1 or more methods of data collection for assessment of learning; link module activities assessments to learning outcomes	Continued work on learning outcomes and linking learning outcomes to appropriate activities & assessments
Example Excerpts	"Expectations for grading weren't clear" "Projects outlined in the beginning, but what was taught did not align with project"	"Syllabus needs to be provided—background information, i.e., suitable intro to LCA; # of assignments and due dates; grading rubrics—to clarifying expectations" "Good supplemental readings, but link back to lectures"
Category of Investigation: Content		
Construct	*No recommendations*	*No recommendations*
Category of Investigation: Instructional Strategies		
Construct	Increase student engagement, i.e., singular project/issue among class, students address from different perspective/dimension; attend classes, share research, offer opportunities for interaction; discuss readings from case studies in small groups	Minimal, yet continuous improvements; increase coordination between instructors and among modules

Example Excerpts	"Consider singular project among class, rather than multiple projects in each class—one, addressed from a different perspective, solution, dimension, etc." "Consider student rapport issues and appropriateness of comments"	"Final deliverable from one module and transfer it to another module to improve upon" "Talk to each other before class—shows integration, organization, clarity, and understanding of expectations"

Faculty Online Survey Findings

The online survey for faculty was focused upon assessing faculty perceptions of the following: 1) achievement of the pre-determined goals for the modules and 2) whether the goals are appropriate for the EEE graduate program. Additionally, faculty were asked for suggested improvements for the modules. Responses were qualitatively coded, and the following results were provided at the May 2017 faculty retreat (Figures 1, 2).

Are the modules effectively accomplishing these goals:
1) give every EEE student broad exposure to EEE topics, and
2) introduce all EEE students in their first year to as many EEE faculty as possible?

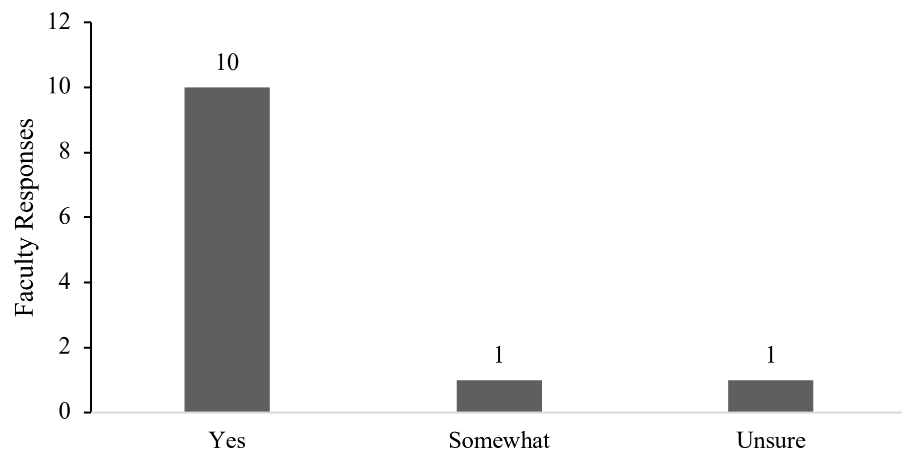

Figure 1: Faculty perceptions on the achievement of the pre-determined goals for the modules.

Are these program goals appropriate or an interdisciplinary program such as EEE?

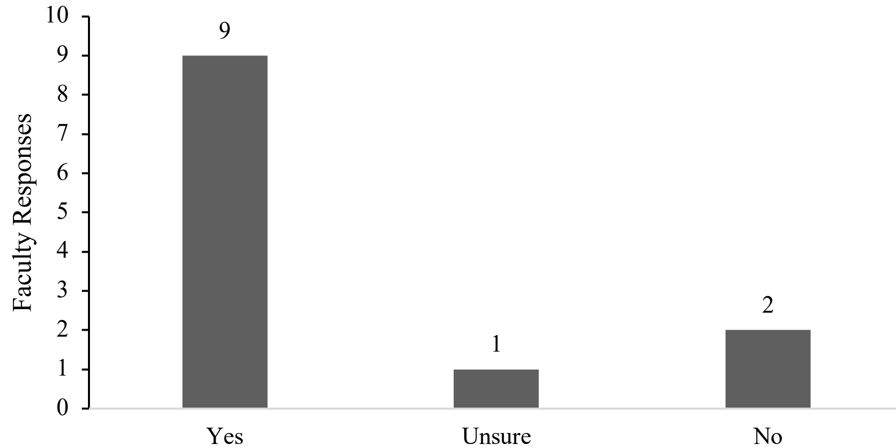

Figure 2: Faculty perceptions whether the goals are appropriate for the EEE graduate program.

Three key suggestions for improvement emerged from the faculty: 1) collaborate and integrate with each other as co-instructors; 2) align activities, learning outcomes and assessments within each module; and 3) consider a thematic approach across the semester.

Additional discussion about improving the modules occurred within the realm of the EEE Academics Committee. In May of 2018, the committee met to consider the faculty discussion from an April 2018 meeting on curriculum, specifically, the one credit modules. The committee reviewed the prior two years teaching commitments of EEE faculty for this course, as well as the notes and handouts from the May 2017 EEE retreat, which included data from focus groups with both students and faculty. At the May 2017 faculty retreat, there was very strong consensus to make improvements to the modules, but not major changes. Specifically, the faculty embraced the idea of coordinating among faculty and making modules in one semester thread together across one thematic topic.

These suggested improvements were developed and implemented during the 2019-2020 academic year. By unanimous consent of the committee, an EEE Task Force, comprised of EEE faculty and graduate students, was established and charged with seeking input and developing a plan to facilitate the improvement of the modules. During the Fall 2018 semester the task force met multiple times and developed a "Memorandum of Understanding for Teaching and Learning" aimed at improving the modules during the 2019-20 academic year (see Appendix C). The MOU explicitly addresses the recommendations shown in Table 4.

Student Online Survey Findings

The online survey for students was focused upon assessing student perceptions on the following: 1) clarity of expectations, 2) effectiveness of team teaching, and 3) integration of a theme across modules. Responses were qualitatively coded. In regards to clarity of expectations, there was a nearly even split in perceptions. Fifty-five percent felt as though expectations were clear, while 45% did not. The same was true for effectiveness of team teaching with 50% of respondents believing team teaching was effective, while 50% did not. However, integration of a thematic approach across the semester was perceived to be effective with 80% agreement among respondents. Additionally, the following recommendations and example excerpts for improving the modules emerging from the survey are listed below (Table 5).

Table 5: Recommendations based upon student focus group feedback.

December 2019 Recommendations	
Category of Investigation: Expectations	
Construct	Clarify expectations among faculty; increase communication between modules, specifically among faculty; increase clarity in grading
Example Excerpts	"That all of the professors get together to create a schedule for homework assignments, project deadlines, and a grading rubric for each module" "The grading rubric for each module would change, deadlines/instructions for certain assignments weren't always specified"
Category of Investigation: Team Teaching	
Construct	Increase coordination between instructors and among modules; share content; consider one overarching syllabus
Example Excerpts	"Sharing materials and assignment information between modules" "Having the previous module instructor provide a brief outline of assignments and major takeaways from the course to the upcoming instructor"
Category of Investigation: Thematic Approach	
Construct	Increase clarity in connection between modules
Example Excerpts	"Some modules were in continuity others weren't" "Providing whole-modules alignment syllabus (in one)"

6. Conclusions and Recommendations

Based on student and instructor feedback, the module format is meeting the objectives of a foundational course for environmental engineering graduate studies. The modules are regularly evaluated by both students and faculty. After the first cycle of modules (Spring 2016-Spring 2019), a formal statement of implementing changes took effect, through a Memo of Understanding (MOU). The MOU addresses expectations of student work and performance, the effectiveness of team teaching, and strengthening thematic connections between modules, and recommendations are being implemented during the 2019-2020 academic year. The MOU specifics a 2 year cycle of themes. Additional student and faculty feedback will be sought at the conclusion of the current cycle of modules (after May 2021).

Graduate programs in EEE related disciplines may consider adapting the module format describe here, if they wish to address the challenge of very diverse preparation in their incoming graduate students, and as a mechanism for integrating the breadth of EEE faculty expertise into a first-year course. The module courses also serve as a pathway into more specialized courses in the graduate program.

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Appendix A

EEE Graduate Program Learning Outcomes

The faculty approved learning outcomes for the graduate degree program in Environmental and Ecological Engineering are adapted from the Environmental Engineering Body of Knowledge developed under the auspices of the American Academy of Environmental Engineers & Scientists.

Outcome 1: Basic Environmental Math and Science

Graduates of the Master's and Ph.D. program in Environmental and Ecological Engineering must have an ability to apply mathematics, physics, chemistry, biology, ecology and earth science knowledge to analyze coupled natural and engineered systems and to design, construct and manage strategies that promote stewardship of the environment and ecosystems.

Outcome 2: Design and Conduct Experiments

An experiment is a procedure to take measurements or model a system in order to test or establish understanding of a process. Graduates of the Master's and Ph.D. program in Environmental and Ecological Engineering must have an ability to design and conduct experiments necessary to gather data and synthesize information for use in analysis and design.

Outcome 3: Use of Modern Engineering Tools

Graduates of the Master's and Ph.D. program in Environmental and Ecological Engineering must have an ability to apply measurement, modelling, statistical and risk analysis tools and techniques required for engineering practice.

Outcome 4: Risk, Reliability and Uncertainty

Graduates of the Master's and Ph.D. program in Environmental and Ecological Engineering must have knowledge of the risks associated with human or environmental exposure to contaminants in our environment and incorporate sound uncertainty and reliability principles into engineered systems that are designed and managed for the protection of ecosystems and human health, welfare and safety.

Outcome 5: Problem Formulation and Analysis

Graduates of the Master's and Ph.D. program in Environmental and Ecological Engineering must have an ability to assess engineering challenges, effectively communicate complex problems, formulate and evaluate alternative management strategies and recommend professionally acceptable solutions.

Outcome 6: Design

Graduates of the Master's and Ph.D. program in Environmental and Ecological Engineering must have the ability to engage in creative and critical thinking, incorporation of uncertainties and use of engineering judgment to design a system, component or process to meet desired needs for the protection of ecosystems and human health, welfare and safety.

Outcome 7: Sustainability

Graduates of the Master's and Ph.D. program in Environmental and Ecological Engineering must integrate the principles of sustainability into analysis and design. Constraints imposed by the long-term sustainability of our natural and social systems must be a critical factor in the design and selection of engineered systems.

Outcome 8: Societal Impact and Environmental Policy

Environmental and Ecological Engineers are regularly involved in the implementation of public environmental policy. Graduates of the Master's and Ph.D. program in Environmental and Ecological Engineering should recognize societal impacts of engineering activities, should communicate these impacts to stakeholders, including policy makers, and should consider stakeholder inputs in developing engineering solutions.

Outcome 9: Globalization and other Contemporary Issues

Graduates of the Master's and Ph.D. program in Environmental and Ecological Engineering must be able to function in a globalized system of development and delivery of professional services, taking into consideration local cultural norms for values, beliefs, communication and technology. Maintaining awareness of emerging contemporary issues and their impact on the profession is required.

Outcome 10: Thrive in Multi-Disciplinary Teams

The solutions of most engineering problems require the expertise and participation of a variety of disciplines. Graduates of the Master's and Ph.D. program in Environmental and Ecological Engineering must be able to use management and communication skills to create, manage and/or participate in teams composed of professionals from a broad range of disciplines.

Outcome 11: Professional and Ethical Responsibilities

The National Society of Professional Engineers has published a Code of Ethics for Engineers that applies to Environmental and Ecological Engineering. A fundamental canon of this Code is that engineers "Hold paramount the safety, health and welfare of the public." Unique to Environmental and Ecological Engineering is the principle that natural ecosystems support human existence and thus service to the public must include the preservation of species and habitats. In addition, environmental and ecological engineers recognize that all of nature has intrinsic value and that ecological stewardship and preventing the destruction of the natural environment is part of their professional responsibility.

Outcome 12: Effective Communication

The environmental and ecological engineer has a critical role interpreting environmental policy issues and implementing of strategies for protecting public health and the environment. Graduates of the Master's and Ph.D. program in Environmental and Ecological Engineering must effectively communicate in an appropriate and understandable manner when interacting with the non-technical public as well as the technical community.

Appendix B

Core Topics List (alphabetical order)

Advanced oxidation and disinfection
Air pollution control and air quality management
Coupled systems, resilience/robustness/fault tolerance
Data analytics
Dynamic system interactions and modeling tools
Eco-design
Engineered biological processes
Environmental biological processes
Environmental chemistry
Environmental modeling
Experimental design principles
Global energy, carbon footprints, global water footprints
Green chemistry and materials
Hydrology and hydrogeology
Industrial ecology concepts
Industrial sectors, supply chains
Life cycle assessment and modeling tools
Mass transport, particle separation
Membrane processes
Multi-criteria decision making
Phase transfer
Product life cycles, material and energy flow analysis
Reactor theory
Remanufacturing, recycling and End of Life
Risk assessment and toxicology
Solid waste and hazardous waste
Sustainability concepts (triple bottom line)
Sustainable manufacturing
Systems thinking tools
Urban ecology

Appendix C

EEE 560 Modules: Preamble & Memorandum of Understanding for Teaching & Learning
Presented by EEE 560 Task Force: Davies, Jafvert, Mashtare, Payne, & Wang
October 2018

Preamble

The EEE Academics Committee met May 1, 2018 to consider the discussion from the April 13, 2018 EEE faculty meeting on curriculum, and specifically, the EEE 560 one credit modules (Table 1). The committee reviewed the prior two years teaching commitments of EEE faculty for this course, as well as the notes and handouts from the May 2017 EEE retreat, which included data from focus groups with both students and faculty. One year ago, there was very strong consensus to make improvements to EEE 560, but not major changes. Specifically, the faculty embraced the idea of coordinating among faculty and making modules in one semester thread together across one thematic topic. These suggested improvements were not developed during the 2017-18 academic year.

On April 13, 2018, the EEE Academics Committee agreed that EEE 560 is important for establishing the identity of the Environmental and Ecological Engineering graduate program. By unanimous consent of the committee, an EEE Task Force, comprised of EEE faculty (Payne, Mashtare, and Jafvert) and graduate students (Wang and Davies), was established and charged with seeking input and developing a plan that will facilitate the improvement of EEE 560 modules. During the Fall 2018 semester the task force met multiple times and developed the following "Memorandum of Understanding for Teaching and Learning" for the EEE 560 Modules aimed at improving the modules during the 2019-20 academic year (Page 2).

Table 1: EEE 560 Modules Complete List of Offerings

	Course Title	Semester(s) Taught (*to be taught)
1	Direct Potabilization	Spring 2016, Spring 2017
2	Recover Value from Solid Waste	Spring 2016, Spring 2017, Spring 2018
3	Discovering Green Chemistry	Spring 2016
4	The Internet of Sustainability	Fall 2016, Fall 2017
5	Data Analytics for Energy	Fall 2016, Spring 2018
6	Modeling Complexity	Fall 2016, Fall 2017, Spring 2019*
7	Deconstructing a Garbage Gyre	Spring 2017
8	Environmental Impact in Automotive Systems	Fall 2017
9	Coastal Resilience Engineering	Spring 2018
10	Introduction to Environmental Photochemistry	Fall 2018
11	Environmental Engineering Ethics and Society	Fall 2018
12	Membranes for Water Treatment	Fall 2018
13	Photoreactors: Theory and Applications	Spring 2019*
14	Analysis of Water Contaminants	Spring 2019*
15	Environmental & Ecological Regulations & Compliance	Spring 2019*

EEE 560 Modules: Memorandum of Understanding for Teaching & Learning

Overview

As EEE embraces the heritage areas of environmental engineering (water, air, and waste management) and emerging areas in industrial sustainability and resilient systems, the overarching objectives of the six-module sequence are three-fold. First, every EEE graduate student will be exposed to a broad foundation of fundamental principles that will allow students to explore and expand their knowledge beyond their primary interests. Second, every participating EEE faculty member will have the opportunity to introduce new graduate students to their primary area of teaching and research. Third, a community of students will emerge with a shared experience over the breadth of environmental and ecological engineering fundamental principles.

Suggested Module Approach

1. Twelve separate modules will be offered over a two-year period, six per year.
2. Co-teaching of modules is encouraged; however, individual teaching is allowed.
   (Footnote: If a module is co-taught, it is expected that both instructors attend every session and plan instructional strategies collaboratively. Alternatively, consider inviting guest speakers from across campus to present on relevant topics.)
3. Each module will be linked to a semester theme listed below.
4. Course learning outcomes must be both contextual (e.g., LCA) and developmental (e.g., writing skills).
5. Instructors should explore ways to have real-world examples (i.e., case studies) integrated within their modules.

Semester Themes*

Year 1

- **Water** (chemistry, treatment, quality)
- **Sustainability** (LCA, industrial ecology, systems modeling)

Year 2

- **Energy** (Urban ecology, LCA, biofuels)
- **Resources and Residuals** (Solid wastes, plastics, biosolids utilization)

*Some modules may be specific to one theme per year or demonstrate an integration of both themes.

Student Expectations

Students are expected to:

- Hold graduate standing in EEE, or be enrolled in the combined degree program, or have instructor approval;
- Contribute three hours outside of class for every contact hour in class;
- Read relevant journal articles;
- Complete a written and an oral presentation in at least one module;
- Engage fully in class activities; and
- Exhibit critical thinking and professionalism.

Faculty Expectations

Faculty are expected to:

- Align module workload and assessments with expectations that students will contribute three hours outside of class for every in-class contact hour;
- Teach tools and methods aligned to the faculty members' expertise;
- Integrate current real-world, case study examples relevant to the year's theme(s);
- Evaluate one assessment tool for ABET (e.g., oral presentation, written report, use of tools, critical thinking, etc.);
- Assign relevant journal articles for in class discussion or for critical writing assignment(s);
- Integrate and share your own research.

Acknowledgment

I have had the opportunity to read this Memorandum of Understanding for Teaching & Learning and fully understand the requirements as outlined.

____	__________________________
Graduate Student Signature	Date
____	__________________________
Graduate Student Signature (print)	Date
____	__________________________
Faculty Member Signature	Date
____	__________________________
Faculty Member Signature (print)	Date