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Designing and Implementing Integrated Project Based Courses for First- and Second-Year Environmental Engineering Students

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Abstract
Engineering education researchers and engineering accreditation boards have long stressed the importance of preparing engineers for 21st-century challenges by integrating professional knowledge, skills, and real-world experiences throughout the curriculum. This holistic approach enables students to connect various disciplinary content, hone professional skills through practice, and apply their developing engineering competencies to relevant problems and communities. While engineering curricula often incorporate integrated content in final-year capstone courses, earlier integration is frequently lacking. In 2020, Montana State University (MSU) embarked on a five-year NSF-funded Revolutionizing Engineering Departments (RED) project aimed at transforming its environmental engineering program. This initiative supported the development of new integrated and project-based courses to be implemented in the first and second year of the curriculum. All tenure-track faculty in the environmental engineering program participated in a collaborative, iterative process to design project-based courses for first- and second-year students. EENV 102, *Introduction to Environmental Engineering Design and Sustainability*, introduces the field of environmental engineering, sustainability concepts, and engineering tools like Excel and GIS in a project-based learning format. EENV 202, *Sustainable Waste Management*, combines systems thinking concepts, an introduction to ethics and social justice topics, and technical content related to solid and hazardous waste management with a life-cycle assessment project on laboratory waste streams. The initial offering of these courses took place in the 2023-2024 academic year. This paper reviews the design and implementation of these two new project-based courses and shares lessons learned. The findings can guide other programs in collaboratively designing integrated project-based engineering courses (IPBC) for first- and second-year students.

1.0 Introduction

Environmental Engineering (EENV) faculty at Montana State University (MSU) embarked on an NSF-supported Revolutionizing Engineering Departments (RED) project to transform pedagogical culture and practice to better prepare and inspire next-generation environmental engineers. The RED project led to the redesign of the standard engineering program of study, which predominantly requires students to take foundational science and math courses in Years 1 and 2 without providing them with opportunities to connect the technical skills gained in these courses to future engineering-specific professional roles and problem-solving. Students are furthermore provided with limited opportunities early in their academic careers to make connections between technical knowledge and the broader social, economic, and ethical contexts of engineering practice [1]. Engagement of students in professional courses and project-based experiences is typically deferred to the junior and senior years. As a result, students often fail to identify as engineers early in their degree programs, which can lead to attrition [2], [3].

The MSU RED project team members aimed to disrupt the compartmentalization of learning in topic-based courses by introducing integrated project-based courses (IPBC) early in the curriculum. The courses introduce open-ended problems to students that require them to integrate knowledge from multiple disciplines and to consider economic, social, and environmental contexts in their design process [4]. Through project-based experiences, students also develop professional skills (e.g., communication, leadership, teamwork) and identity through exposure and practice [5]. This paper describes the process used to integrate desired learning outcomes across the curriculum by developing and implementing new required IPBC courses for first- and second-year environmental engineering students. A companion paper [6] describes the impact of these IPBC courses on professional identity formation, a key outcome for this RED project.

2.0 Methods

The EENV faculty determined three pillars of competency essential to a modern environmental engineering practitioner which connect all the outcomes in the program: *systems thinking*, *professionalism*, and *sustainability* (Figure 1). As described previously [7], [8], [9] the three pillars describe the values and skills our students will need in their environmental engineering careers. The professionalism pillar includes leadership development with outcomes related to communication, ethics, social justice, and teamwork. The systems thinking pillar incorporates context-based design, i.e. connecting engineering projects and decision-making to broader social, economic, and environmental systems. The sustainability pillar navigates the environmental, social, technical, and economic contexts with outcomes related to infrastructure, society, and sustainable development. These three pillars form the foundation for the outcomes and content integrated into the two new 1st and 2nd year courses described in Section 3.0.

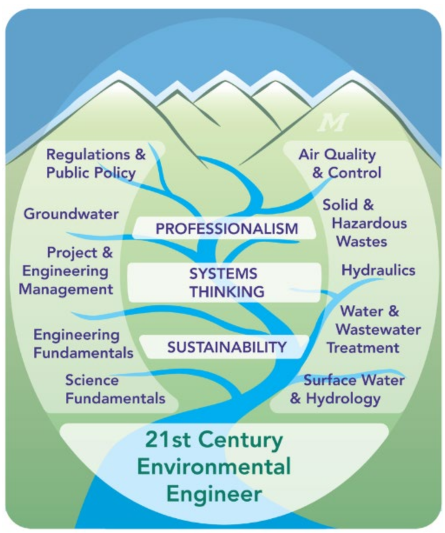

Figure 1 – Integrated undergraduate engineering model showing pillars of competencies.

Our RED team began the curriculum change project by deconstructing our existing curriculum and identifying over 400 concept-level outcomes [7], [8]. Many of those outcomes were in the existing curriculum and some, particularly those related to non-technical content, were new. Some courses were modified so that technical content was offered as early as possible and at an appropriate level in Bloom's taxonomy. One new technical course, ECIV 231, Introduction to Engineering Hydrology, moved content previously reserved for the 3rd year of the curriculum to the 2nd year. Additionally, EENV faculty developed two new project-based courses to address learning outcomes that were not adequately covered in other courses. The courses were designed for the 1st and 2nd years to enhance our students' connection to their engineering identity early in their programs of study. EENV 102, Introduction to Environmental Engineering Design and

Sustainability, introduces the field of environmental engineering, sustainability concepts, and engineering tools like Excel and GIS in a project-based learning format. The primary professionalism learning outcome emphasis in EENV 102 was communication. EENV 202, Sustainable Waste Management, combines systems thinking concepts, an introduction to ethics and social justice topics, and technical content related to solid and hazardous waste management with a life-cycle assessment project on laboratory waste streams. The primary professionalism learning outcome emphasis in EENV 202 was teamwork.

The MSU RED team developed guidelines for the collaborative development of outcomes and course content for EENV 102 and 202, which enhanced faculty understanding of the programmatic outcomes, their placement in the curriculum, and what content was instructed in the new courses. For course outcome development, it was determined that for team-taught project-based courses in the EENV program, outcomes would be developed and adopted by the core RED team with input from collaborating faculty as needed and that once adopted, course outcomes would not be changed except by re-approval of the core team. In the co-development of courses, the faculty for team-taught IPBC courses utilized the outcomes adopted by the RED team to develop a course syllabus that outlined course content. The syllabus included a weekly schedule of topics, descriptions of the project-based activities, and a description of assessment measures which were reviewed, modified, and/or approved by the core EENV faculty team a minimum of three months before the course offering. Once approved, the lead faculty developed the course in a manner and time they found mutually agreeable with assistance and input from the core team as needed.

In summary, the core EENV faculty team established the fundamental values or pillars of the environmental curriculum as a whole and then developed a comprehensive learning outcomes database to identify where desired skills or outcomes were included or missing in the curriculum. They then developed a method to build new courses and a plan for putting together the content and projects for the new first- and second-year environmental engineering courses. These courses were first implemented in the 2023-2024 academic year and a description of the outcomes, content, projects, and lessons learned follows in Section 3.0.

3.0 IPBC Discussion

One overarching goal of implementing project-based courses in the first and second year of the curriculum is to motivate students with diverse skills and backgrounds to continue to pursue environmental engineering. Too often, students with less experience in technical subjects, such as calculus or chemistry, fall behind their peers in courses and may begin to feel as if engineering is “not for them” [10], [11]. Our new courses, EENV 102, Introduction to Environmental Engineering Design and Sustainability, and EENV 202, Sustainable Waste Management focused on developing holistic engineering skills in our students so that they recognize that teamwork, communication, creativity, and problem-solving are critical skills for an engineering career. EENV 102 was delivered for the first time in the Fall of 2023 and EENV 202 was first delivered in the Spring of 2024. The courses also expose students to diverse career paths in environmental engineering through projects, tours, interactions with guest speakers, and career panel sessions. In the following sections we describe the design and implementation of the courses by sharing the outcomes and content, key projects or assignments, the methods used in assessment, some of the student feedback from each new course as well as lessons learned from the instruction of these new courses.

3.1 IPBC Outcomes and Content

3.1.1 EENV 102

The primary goal of the EENV 102 course was to introduce the core environmental engineering values of systems thinking, sustainability, and professionalism through real-world projects requiring the application of engineering tools, communication, and design. In EENV 102, the focus of the integrated content included: systems thinking, sustainability, communication, environmental engineering careers, and engineering tools (Excel and GIS). The skill of communication was emphasized in several of the key assignments to better stress the need for professionalism, one of the central pillars discussed in the methods section (2.0). The following outcomes were determined by the core EENV faculty. By the end of the semester, students should be able to:

1. Describe career paths in environmental engineering and typical roles of environmental engineers.
2. Identify fundamental concepts of sustainability and systems thinking important in environmental engineering.
3. Demonstrate the ability to communicate effectively.
4. Identify potential impacts to stakeholders of an environmental project and describe the ethical dimensions of the project.
5. Recognize and apply engineering tools commonly used in environmental engineering projects.

Communication was an important aspect of this course. Our students, instructors, and technical advisory committee regularly identify this as a weakness. This issue is compounded by many students' perception that engineers do not need to be good at writing and communication if they have strong technical skills. To address this, we developed in-class activities and assignments to help students explore the ways that engineers communicate with each other, their clients, and the public. Students were given feedback on assignment drafts and time in class to work on their writing as described in Section 3.2.1. The following topics were introduced in the course (Table 1).

Table 1. Schedule of topics covered in EENV102

Week	Topic
1-2	Introduction to Environmental Engineering
3-4	Introduction to sustainability
5-6	Introduction to Life Cycle Analysis and environmental footprints
7-8	Integrating sustainability with engineering design (project 1)
9	Introduction to engineering ethics
10-13	Introduction to engineering tools – GIS and Excel
14	Integrating engineering tools and sustainability (project 2)
15	Course wrap-up and Project Presentations

The course was team-taught where one faculty member led the first half of the semester and the first project, and the second faculty member led the second half of the semester and the second project. However, both faculty were involved in the development of all course content, were present in the classroom, and participated in class discussions and activities throughout the semester. The course was supported by four upper-level undergraduate teaching assistants and there were approximately 60 students in the first offering. The key assignments (projects) are described in section 3.2.1.

3.1.2 EENV 202

The primary goal of the EENV 202 course was to expand on the core environmental engineering values gained in EENV102 and apply the fundamental concepts of systems thinking, sustainability, and ethics to environmental engineering projects focused on solid and hazardous waste management. The focus of the integrated content included: systems thinking, sustainability, environmental engineering ethics, social justice, teamwork, material life cycle assessment, and waste management methods. By the end of the semester, the following outcomes were identified as desirable for the students to achieve:

1. Identify and explain how wastes are classified and stored, as well as how they can be utilized as resources in modern society.
2. Apply a systems thinking approach to assess the sustainability of waste management systems.
3. Explain the fundamentals of life cycle thinking in the context of sustainability and the steps and methodology used in life cycle analysis.
4. Recognize how bias and inequality can occur in engineered systems and explain how stakeholders can be impacted.
5. Recognize and develop positive teamwork skills and behaviors.

Teamwork was an important element of this course. Surveys from employers consistently rank team skills as one of the critical abilities they look for when recruiting. According to our technical advisory committee, the ability to work well in teams is one of the biggest gaps between the skills that graduates have and what the industry requires. Team building was a large element of the course, and the ability to function well on a team was evaluated as part of the course grade. Assessment of teambuilding and functioning is described in section 3.3.2.
The following topics were covered in the course (Table 2).

Table 2. Schedule of topics covered in EENV 202

Week	Topic
1	Course introduction
2	Overview of waste types and management
3	Systems thinking and ethics
4 - 5	Raw materials and waste streams
6	Project introduction
7 - 9	Life cycle assessment
10 - 11	Waste disposal facilities and social justice
12	Communication resources for project deliverables
13	Social and environmental justice
14	Composting, recycling, and resource recovery
15	Course conclusion and review
16	FINALS- Poster session

The course was team-taught where each faculty member co-directed the project and presented lecture content based on their expertise and skills. Typically, each instructor presented content once per week (either in the Tuesday or Thursday class block). The course was supported by a graduate student teaching assistant.

3.2 IPBC Projects and Key Assignments

3.2.1 EENV 102

In the first project, the students were tasked with giving input on the sustainability features of a new on-campus hotel, which is currently in the planning stage. Students were asked for input on what features of the building design and operation would increase the sustainability of the hotel in four categories: 1) water and wastewater features of the 150 hotel rooms, 2) landscaping and stormwater features, 3) energy use for both heating/cooling and electricity, and 4) waste generation. Students worked in teams for this project with each member of the team focused on one of the four features. During in-class activities the students formed additional expert teams with students working on the same topic to provide support and feedback. To expand students' technical understanding of the topic, the instructors arranged a tour of sustainable building features on campus with facilities engineers. Students worked in groups and conducted interviews with campus representatives to assess their design alternatives. At mid-term students were tasked with communicating their findings in oral presentations by using: a poster or other visual medium, PowerPoint presentation, video, or short audio podcast. In addition, the students prepared a written memo with their recommendations. The assignment was structured so students received feedback on partial deliverables as they worked on their written and oral communication skills.

In the second project, the students were focused on designing for climate resiliency, by advising the City of Bozeman on a preliminary design concept for a bridge repair/replacement on a local creek several miles from campus. Students worked independently on this project to assess their individual skill development. Students were given the constraint that the City of Bozeman needs to balance the cost of the project and the need for access by local businesses and residences with the desire of local NGO stakeholders to preserve the aquatic ecosystem and natural river function. Preliminary background research was conducted by students using online GIS sites, documentation from the Gallatin Country Bridge Department, and reports of previous stream restoration work on Bozeman Creek. Students traveled to the site to evaluate geomorphic features of the stream such as bankfull flow width, estimate stream flow, measure water quality parameters, and assess the bridge upgrade requirements. Students analyzed average streamflow data from a nearby river gauge using Excel, consulted recent Montana and Regional Climate Assessments to gain an understanding of forecasted precipitation trends, and used StreamStats (https://usgs.gov/streamstats) to obtain an estimate of design flows based on existing regression relationships. Students were asked to provide their recommendation for the bridge design flow rate under climate change and to justify whether they would recommend repair, removal, or replacement of the existing single lane bridge, which is under capacity.

To evaluate the second project, the students were required to submit a memo addressed to the City of Bozeman and an accompanying single-page informational sheet that describes their suggestions that could be handed out at public hearings. Based on feedback from our external advisory board, who indicated that recent student graduates had a difficult time communicating orally with other engineering professionals, a unique communication assignment was developed as part of this project. Students were required to make an appointment in-person at the front desk of the Civil Engineering Department to meet with the department chair who was previously the Public Works Director for the City. The chair gave the students feedback on their design and asked them questions related to the three pillars of sustainability to make sure students were considering all important aspects of the project. This three-part approach (development of a memo, preparation of a fact sheet, and meeting with a senior engineering professional) enhanced communication skills with different audiences.

3.2.2. EENV 202

While developing the project for EENV 202, instructors conducted a laboratory waste audit in their own research laboratories. Based on this waste audit, four products commonly used in the laboratory were selected to analyze with a life cycle assessment (LCA) for the project. These products are paper towels, aluminum foil, pipette tips, and nitrile gloves. An LCA is a systematic analysis of the environmental impacts of a product over its whole life cycle, including raw materials extraction, manufacturing, distribution, use, and final disposal. In this project, student teams used a software tool, EarthSmart, to build LCA models of the four products identified from the laboratory waste audit. EarthSmart is a user-friendly interface LCA modeling tool, developed by EarthShift Global (https://earthshiftglobal.com/earthsmart-login). The objectives of this project were for students to practice life cycle thinking, apply systems thinking to a product life cycle model, apply an iterative model design and analysis approach common in engineering practice, and build teamwork skills.

Students were assigned to a 4-person Home Team where each team member was responsible for building an LCA model of one of the four lab waste products. Students working on the same product formed separate Expert Teams to provide collaboration and support for the research and inventory analysis phase of the project. Each team member was responsible for sharing their model with the other members of their Home Team so that all students could learn about all the products' life cycles. Project deliverables were tied to the Home Teams. Home teams presented posters during the final exam period to explain their LCA analysis and make their recommendations for improving sustainability.

3.3 IPBC Assessment Methods

3.3.1 EENV 102

In both projects, a holistic rubric approach was used, where the following competencies were assessed: 1) technical accuracy, 2) stakeholder discussion, 3) supporting information for recommendations, 4) grammar and writing, 5) technical writing quality, 6) use of citations, 7) presentation of recommendations, and 8) discussion of three pillars of sustainability (Project 1) or discussion of ethical aspects of the project (Project 2). Students were scored 1-4 with one (1) being assessed as unsatisfactory and four (4) being assessed as exceeding expectations. Holistic rubrics are useful because they can be designed to blur lines between the technical and communication portions of the assignment which in practice is often true [12]. In addition, presentations were assessed using holistic rubrics in conjunction with evaluation using PitchVantage, a commercially available presentation skills assessment and practice software that has 3D simulated audiences, who react to the user's performance so that students can practice and improve presentation skills (https://pitchvantage.com/).

3.3.2. EENV 202

The Comprehensive Assessment of Team Member Effectiveness (CATME) was used to evaluate the teaming behaviors. CATME, software developed at Purdue University, allows instructors to 1) assign students to better-functioning teams 2) train students to work in teams, 3) identify teams having teamwork difficulties, and 4) train students to rate teamwork behaviors (www.catme.org). All student surveys and Home Team assessments were conducted using CATME. Peer and self-evaluations were conducted at least three times during the semester. These evaluations were used to determine students' grades for the Teamwork component of the final semester grade. Students were assigned to a Home and Expert team for the semester. In retrospect, it would have been useful to also be able to track and evaluate the functioning and performance of the Expert teams as this is where students did most of their work on their LCA models.

The final project deliverable was a poster session where the four-person team was assigned to deliver one poster in person to the department faculty and stakeholders from around campus who had an interest in laboratory sustainability. To evaluate their individual contributions, each student was assigned an individual presentation of the poster through PitchVantage. Rubrics assessing communication effectiveness and technical accuracy were developed and shared with the students at the time the assignment was given so expectations were clear. Holistic rubrics were used to evaluate individual and group presentations.

3.4 Student Feedback

Students had positive and constructive feedback for the two new courses. One student, after a field trip as part of the first-year project course, conveyed that "I felt like a real engineer!". Another student when asked about their first-year project-based course experience replied "So far, the courses required, specifically EENV 102 and 202 have been my favorite courses, and have made me feel more confident about my decision to pursue an Environmental Engineering degree. I am very grateful to have had Dr. Lauchnor and Dr. Plymesser as professors and to have two women to look up to in my field of engineering.” Yet, the students also recognize that project-based courses are challenging, and one student mentioned, “I soon realized that I was much more capable than I initially thought, and it turns out that was their (instructors) plan all along. They knew that the open-ended nature of the projects would be difficult, but that conditioned us to go more in-depth and [ask] more thoughtful questions to get the clarity that we needed. The confidence that I gained from the open-ended and seemingly difficult projects carried with me”.

4.0 Lessons Learned

First-year students in the EENV 102 course benefited from instructors sharing their struggles, fears, and insecurities related to engineering careers. In the first offering of the course, we did not share this until the end of the semester and several female students thanked us for helping them feel less alone in their worry about belonging. In future offerings, we will be more forthcoming about normalizing the struggle with finding an engineering identity.

There were some course features that we (the EENV 102 instructors) in error assumed that first-year students understood. An example of this was office hours. As is typical at the beginning of the course, instructors shared their office hours and encouraged students to attend. Later in the semester, it became clear that some students did not understand that an appointment is not required for office hours or that they could simply stop by with a question without checking in first by email. The instructor teams will continue to uncover and demystify these hidden curricula to help level the playing field for all students.

It was valuable to have advice from the EENV 102 instructors as the EENV 202 instructors developed the course content and schedule for the first offering. For example, after gathering feedback from the EENV 102 instructors, EENV 202 instructors designed more time in class for students to work with their Home or Expert teams. They also took time at the beginning of the semester to instruct the students on the art of connecting with faculty during office hours. These were valuable pieces of information for the development of the second-year course and all faculty continue to share these nuggets of advice as further offerings of the courses are planned and executed.

When the RED team took on the curriculum and cultural change project in the environmental engineering program, they wanted to incorporate team teaching by the core faculty in each of the project-based courses. However, given the small number of faculty, the desire for team teaching and workload constraints may be in opposition, especially after the end of the RED project support. The core RED team has discussed options and offered some ideas for the implementation of future course development or offerings. One idea would be that the team always works to develop new courses collaboratively in a curriculum committee, but that team teaching may only be implemented for a new class the first time it is offered. Another option, which was piloted in the Fall of 2024 in the EENV102 offering was to use the team-teaching opportunity to additionally support graduate students with teaching experiences. In the fall of 2024, the EENV 102 course was instructed by a senior tenured faculty and a soon to graduate PhD candidate. This approach might be challenging in semesters where graduate students are not available or have less interest in teaching. Finally, other methods to support instructors who are teaching one of the project-based courses independently include finding dedicated graduate student TA support or pursuing workload reductions in other aspects of their appointment, such as reducing their advising and committee workload in that semester.

The first instruction of these project-based courses was demanding, and the instructors look forward to sharing their successes and challenges while evolving and implementing best practices and innovations in future offerings.

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