BOARD #155: Assessing the impact of project-based courses for engineering professional identity formation in 1st and 2nd year environmental engineering students

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Abstract

In 2020, Montana State University initiated a five-year NSF-funded Revolutionizing Engineering Departments (RED) project to transform its environmental engineering program. We hypothesized that engaging students with real, integrated engineering content in the first years of the program would help them build an engineering professional identity (EPI) and improve student retention and success. Two new project-based courses for 1st and 2nd year students in the environmental engineering program were developed and offered for the first time during the 2023 – 2024 academic year. The two courses integrated content on sustainability, professionalism, systems thinking, ethics, and social justice topics, with technical content on engineering design and tools. Surveys were given to the environmental engineering students enrolled in these new 3-credit courses, along with two cohorts of 1st year students in a 1-credit introductory civil engineering course (the control group) who were not enrolled in the new environmental engineering courses. All surveyed students were asked to rank which EPI pillar of Professionalism, Systems Thinking, and Sustainability (as defined by our RED project) was most valued by their field of engineering. A second question asked them to rank the EPI competencies presented – technical knowledge, systems thinking, public policy, management, communication, ethics, teamwork and social justice – according to which ones best prepare(d) them to be an engineer. Students were surveyed at the beginning and end of the semester. This paper presents the extent to which students' perceptions of the most and least important EPI pillars and competencies changed over the semester. We found that there was little change across all groups with respect to which pillars were most valued, with Sustainability being reported of highest value and Professionalism of lowest value to both Civil Engineering and Environmental Engineering students. For students in the control Civil Engineering course, students' perceptions of EPI competencies that prepared them most and least for being an engineer, technical knowledge and social justice respectively, did not change over time or across the two cohorts. For Environmental Engineering students, however, there were differences in students' perceptions between the classes and over time. Students in the 1st year course reported that communication was the most important engineering competency at the beginning of the semester but reported a tie between technical knowledge and systems thinking at the end of the semester. Social justice ranked lowest in both pre- and post-course surveys for 1st year students. At the beginning of the semester, students in the 2nd year course ranked technical knowledge highest and social justice lowest. By the end of the semester in the 2nd year course, ethics ranked highest and management ranked lowest. These results suggest that the RED project-based courses were more effective than the control course at challenging and building upon students' initial perceptions of engineering values and competencies, and that repeated exposure to integrated project-based courses may enhance this effect.

1. Introduction

1.1 Background and Motivation

In 2020, Montana State University initiated a five-year NSF-funded Revolutionizing Engineering Departments (RED) project to transform its environmental engineering program. We hypothesized that engaging students with problem-based, integrated engineering content in the first years of the program would help them build an engineering professional identity (EPI) and improve student retention and success [1-5]. The goal of the RED project was to elevate other aspects of environmental engineering practice in addition to the traditionally-valued technical knowledge inherent to engineering professions. The project team identified three EPI pillars critical to the formation of 21st century professional environmental engineers: systems thinking, sustainability, and professionalism where professionalism encompasses communication, ethics, teamwork, and management/leadership skills. Two new integrated project-based courses were developed and implemented in the 1st and 2nd year of the curriculum. This study explores the extent to which students recognize value in specific non-technical and multidisciplinary aspects of engineering practice as they begin to develop their conception of the profession of engineering. We also set out to understand how and when interventions designed by the RED project team are influencing student conceptions about what it means to be a professional engineer in the 21st century.

1.2 Engineering Professional Identity (EPI)

The concept of engineering identity has become a central focus in the research on engineering education, with significant attention given to how individuals perceive themselves as engineers, both during their educational journey and as they transition into professional practice [6]. Engineering identity refers to how individuals perceive themselves as engineers, both in terms of their academic role and their professional role [3, 7-9] . Previous studies on engineering identity have focused on academic aspects, e.g., students' math or science identity [10]. As noted by Villanueva et al. [11], engineering identity is not static; it is a dynamic and evolving construct shaped by individual experiences, social interactions, and institutional contexts. Engineering identity is not merely about technical expertise; it is also about developing a sense of belonging to the engineering community and aligning oneself with its norms, values, and practices.

Recent literature highlights the importance of academic experiences in the formation of engineering identity. These experiences can include problem-solving tasks, group collaborations, and mentorship, which contribute to the development of both technical and personal competencies [8, 11, 12]. For many students, engineering identity is closely tied to their engagement in authentic engineering practices that enable them to see themselves as part of the larger engineering community. This process is often facilitated by experiential learning, hands-on projects, internships, and interactions with peers and faculty members who serve as role models.

Within the context of engineering identity, the concept of *engineering professional identity (EPI)*, in particular, has emerged as a key area of study in understanding how students and professionals internalize the values, behaviors, and responsibilities of the engineering profession [10, 13]. It is a dynamic and multifaceted construct shaped by personal engagement, social interactions, and systemic influences encountered throughout educational and professional experiences [14]. Understanding EPI is vital in fostering a sense of belonging, professional commitment, and effective integration into the engineering workforce.

EPI specifically refers to the internalization of the norms, ethics, and responsibilities associated with being a practicing engineer. It represents the transition from being an engineering student to becoming a professional who is responsible for applying engineering principles to solve real-world problems [3, 5, 9, 12, 13, 15, 16]. Villanueva et al. [11] underscore that the development of professional identity is a complex, iterative process that spans an individual's education and career trajectory. Evidence indicates professional identity formation occurs when students engage in educational experiences that are open-ended and do not produce specific answers or set outcomes [17]. As students progress through their educational experiences and begin to practice as engineers, they encounter challenges that test and shape their professional identity.

The development of engineering professional identity is underpinned by various theoretical frameworks and grounded research methodologies that offer comprehensive insights into how this identity forms and evolves. Villanueva et al. [11] propose a working definition of EPI that integrates individual, social, and systemic sources of influence. This framework is informed by historical perspectives on engineering education, categorizing professional identity into three roles: Mediator, Designer/Tinkerer, and Social/Servant. These roles reflect the evolving nature of the engineering profession, from technical problem-solving to societal service roles, and shape how students perceive their future roles as engineers.

This paper presents the results of a survey, which explored the extent to which students' perceptions of the most and least important EPI pillars and competencies changed over a semester. Surveyed students included those enrolled in an introductory Civil Engineering course (control group), and students in two new RED integrated project-based learning courses that were delivered for first year and second year environmental engineering students.

2. Course Descriptions

2.1. RED project-based courses

One overarching goal of implementing project-based courses in the 1st and 2nd year of the curriculum is to motivate students with a range of skills and backgrounds to continue to pursue environmental engineering. Our project-based courses, EENV 102, *Introduction to Environmental Engineering Design and Sustainability*, and EENV 202, *Sustainable Waste Management* integrate introductory-level technical content with interdisciplinary, socio-technical content related to the vital 'soft skills' both the general public and employers expect professional engineers to possess [18]. EENV 102 was delivered for the first time in Fall of 2023 and EENV 202 was first delivered in the Spring of 2024. Both courses consist of 3 credits of lecture and in-class project work sessions. Both are offered once per academic year and are required for Environmental Engineering majors. Enrollment has been approximately 60 students in EENV 102 and 30-40 in EENV 202. Neither course has pre-requisites and both are open to students outside of the various engineering majors.

EENV 102 introduces the core environmental engineering values of systems thinking, sustainability, and professionalism through two projects. In the initial course offering, the first project was a team project related to sustainable design of a proposed on-campus hotel. The second project was an individual project related to bridge design and repair for climate resiliency. Together, the projects required the application of engineering tools like Excel and GIS; visual, written, and oral communication skills; stakeholder analysis; data analysis and design. In addition to the projects, students learned about environmental engineering career paths from guest speakers in a range of professional positions.

The EENV 202 course builds on the core environmental engineering values applied in EENV 102 via a team-based project focused on waste management. The integrated course content included systems thinking, sustainability, environmental engineering ethics, social justice, teamwork, material life cycle assessment, and technical content related to waste streams and management methods. Discussions of waste production and waste disposal are fertile ground for exploring ethical conflicts and the disproportionate impacts that marginalized communities experience with respect to pollution and environmental degradation. The project in the initial course offering was a life cycle assessment (LCA) of four laboratory waste streams. Students presented their final projects in a public poster session to highlight the importance of communication skills in engineering.

2.2. Control course

Students enrolled in an introductory engineering course were also surveyed in this study for comparison. ECIV 101, *Introduction to Civil Engineering*, is a 1st year, 1-credit civil engineering course designed to illustrate the breadth of the civil engineering profession by introducing students to the technical sub-disciplines available in the Department. Guest speakers and instructors introduced Geotechnical Engineering, Structural Engineering, Water Resources (Hydrology and Hydraulics) Engineering, and Transportation Engineering in addition to the separate degree programs in Environmental Engineering and Construction Engineering Technology. The once-weekly lecture course also covers career options in Civil Engineering and introduces topics related to sustainable infrastructure, engineering ethics, and professional practice. Projects in the class recently have included a stakeholder analysis, explanation of transportation design criteria, and a preliminary site design for infrastructure improvements to an arterial road adjacent to campus as well as preparation of a 4-year program of study to complete degree requirements. Enrollment in ECIV 101 during the semesters included in this survey was approximately 160 students. The course is not required but is recommended for students considering majoring in Civil Engineering or a related field. The course is offered in the fall semester and must be taken in a student's first year.

3. Methods

3.1. EPI Pillars and Competencies

In the first year of our RED project, our team identified four high-level thematic constructs to connect the technical and non-technical aspects of engineering practice and encourage students' formation of engineering professional identity. We further developed seven lower-level EPI competencies which are related to the EPI pillars and comprise the non-technical aspects of environmental engineering that our team sought to explicitly highlight in our curriculum. The technical scientific and engineering content knowledge that makes up the discipline of environmental engineering is grouped into an eighth EPI competency, technical knowledge. In this section, we provide our working definitions of the EPI pillars and competencies included in the survey.

The thematic constructs we identified are the EPI pillars of Professionalism, Systems Thinking, and Sustainability along with technical Environmental Engineering competencies. Figure 1 shows the three EPI pillars linking the array of technical knowledge contained within environmental engineering. Our project team developed definitions by consensus for the three EPI pillars, as described in Lahneman et al. 2024.

Figure 1. The Engineering Professional Identity pillars of Professionalism, Systems Thinking, and Sustainability are constructs to connect non-technical concepts to the technical Environmental Engineering competencies.

In our working definitions, *Professionalism* refers to the necessary and important 'soft skills' of communication, engineering ethics, teamwork, and management. Effective communication in this context refers to both technical communication and interpersonal skills like empathic listening and adapting communication styles for the audience. Professionalism for environmental engineers entails cultivating an attitude that values stakeholders and their feedback. *Systems Thinking* recognizes that engineering design exists within a self-sustaining social, economic, and environmental context and effective, sustainable design requires a holistic approach. In our understanding, Systems Thinking requires that environmental engineers apply their technical expertise, analytical tools, and a long-term, comprehensive view to design challenges. In addition to this holistic design approach, we understand Systems Thinking to also pertain to a holistic mindset where interactions between system components are understood to be complex and non-linear whether the system of interest is a natural system like a watershed or a socio-cultural system like a solid waste management system. There was considerable overlap between our team's understanding of Systems Thinking and Sustainability. There was strong consensus among our faculty team that *Sustainability* involves adopting a holistic approach to engineering design and considers the social, economic, and environmental dimensions of a problem to avoid unintended consequences over the long term. We understand that applying systems thinking is a necessary pre-requisite for achieving sustainability and tools like Life Cycle Assessment (LCA) can assist environmental engineers with understanding the system complexity and design for sustainable, win-win solutions. In our definition of Sustainability in environmental engineering, there is also a requirement for strong technical expertise and a mindset that recognizes complexity and values creativity as well as analysis.

The EPI competencies our team identified provide a more granular breakdown of the knowledge, skills, and abilities our students will need to practice effectively as environmental engineers in the 21st century. These competencies are the things we expect our student to actually do, rather than simply be aware of or value. The EPI competencies include technical knowledge, systems thinking, public policy, management, communication, ethics, teamwork, and social justice. Although we recognize that other skills may also be valued in the profession, these competencies were chosen as the focus for survey data collection. *Technical knowledge* refers to the broad body of scientific facts and engineering methods traditionally taught in engineering programs in the United States (e.g., technical mastery expected on the Fundamentals of Engineering examination). *Systems thinking* as an EPI competency, rather than as an EPI pillar, means the ability to identify system components and connections in natural and social systems, and then apply analytical tools and methods, like LCA, to specific engineering problems. *Public policy* refers to an understanding of how public policies and regulations related to engineering are developed and exerted in society, and how engineers in practice interact with public administration at all levels of government. The EPI competency of *management* refers to students' development of leadership and decision-making skills, project and financial management skills like scoping, scheduling, and budgeting, and skills related to management of quality and risk. *Communication* as a competency includes written, verbal, and visual communications with technical and non-technical audiences, as well as skills like listening and giving/receiving feedback. The *ethics* EPI competency entails knowledge of ethical frameworks and professional codes of ethics, the ability to recognize stakeholders, needs, and value conflicts, and the ability to make sound decisions when trade-offs between ethical values are necessary. Our understanding of the *teamwork* EPI competency is informed by the CATME tool developed at Purdue University (https://info.catme.org) and includes a student having the appropriate knowledge, skills, and abilities for the work at hand, contributing to the team's work, interacting effectively with team members, helping keep the team on track, and expecting high quality work from the team. *Social justice* in the EPI competency context refers to our students' ability to recognize bias and inequality in engineered systems, analyze trade-offs, and develop alternatives that promote equity or mitigate adverse social, economic and environmental effects for affected communities.

Broadly speaking, the technical knowledge, systems thinking, social justice, and public policy EPI competencies are relevant to all three EPI pillars of Professionalism, Systems Thinking, and Sustainability. The competencies of communication, ethics, teamwork, and management are primarily contained within the construct of Professionalism (Figure 2).

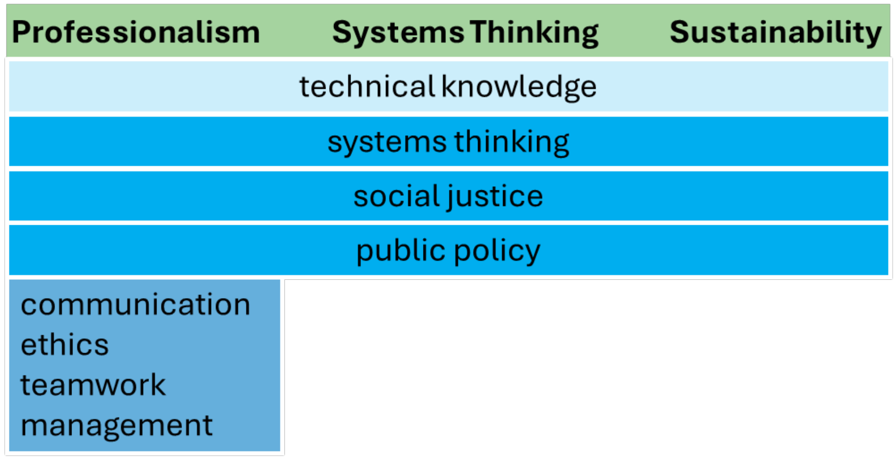

Figure 2. The eight EPI competencies (blue) are related to the three EPI pillars (green).

3.2. Research participants and demographics

Our participants were 295 undergraduate students enrolled in the new project-based courses or the control introductory civil engineering course and who volunteered to complete our survey. Of the pool of participants, 288 provided complete answers to the survey questions reported here. Across all survey respondents, 74% were first-year students, 13% were sophomores, 4% were juniors. The participants were largely distributed among the disciplines of environmental engineering (42%), civil engineering (35%), and construction engineering technology (14%). The participants were overwhelmingly White (81%) and predominantly male (66%). Approximately 8-10% of participants did not respond to one or more demographic questions.

3.3. Data collection materials

We designed a 23-question survey to collect the full data set; a sub-set of that data is reported here. After establishing eligibility in the first three questions, we posed six free-response questions as previously reported by Villanueva [14] to elicit students' perspectives of engineering professional identity. Two questions were related to students' motivation to pursue engineering and their professional goals. Ten questions were related to demographics. This paper addresses the remaining two questions which asked students to rank, in order of perceived importance or value to their chosen field of engineering, the three EPI pillars identified in our RED project (Professionalism, Systems Thinking, and Sustainability) and the eight EPI competencies (technical knowledge, systems thinking, public policy, management, communication, ethics, teamwork and social justice). The survey did not include definitions or descriptions of the EPI pillars or competencies as presented earlier in this paper. We wanted, in part, to ascertain students' progress toward understanding these constructs.

3.4. Data collection

Students in each course were surveyed during the class period, once at both the beginning and end of the semester. The survey was presented to students by a volunteer graduate student who was otherwise not associated with the RED project or the course. Faculty were not present during the survey. Data was collected online using a web-based survey tool (Qualtrics). Students who participated were enrolled in a drawing for a gift card prize as incentive to complete the survey. Participating students may have been enrolled in one or more of the courses over the three semesters when the survey was conducted.

3.5. Data analysis

Participants' responses to the survey questions reported here consisted of numerical ranking of importance, where #1 means most important or valuable. We tallied the number of times students in each course assigned a particular rank to each EPI pillar or competency. The EPI pillar or competency receiving the highest number of #1 rankings was deemed the most important or a valuable concept to students' perception of engineering professional identity. The EPI pillar or competency receiving the highest number of the lowest ranking (#3 for the EPI pillars or #8 for the EPI competencies) was determined to be the least important or valuable in the students' perception. We compared responses from students in the same course at the beginning and end of the semester, as well as responses from students in the control course (ECIV 101) and the RED courses (EENV 102 and 202).

There was a lower response rate at the end of the semester in the EENV 202 course when 9 of 31 enrolled students completed the survey, compared to 26 participating at the beginning of the semester. We present the data from EENV 202 here but note that interpretation of the findings is preliminary and requires validation with additional data to be collected in future course offerings. Response rates in the other courses were similar at the beginning and end of the semester (Table 1). There was overall a higher response rate from students enrolled in the new RED project-based Environmental Engineering courses compared to the control Civil Engineering course.

Table 1. Courses, enrollment, and number of survey respondents.

Course and Semester Offered	Course Enrollment	Responses – Beginning of Semester	Responses – End of Semester
ECIV 101 – F22	156	53	46
ECIV 101 – F23	162	34	33
EENV 102 – F23	58	29	30
EENV 202 – Sp24	31	26	9

4. Results and Discussion

4.1 EPI Pillars

We found that there was substantial consistency across all groups with respect to which EPI pillar was perceived by students to be the most valued, with Sustainability being reported of highest value in each instance (Figure 3 and Figure 4). The only exception was in the Fall 2023 offering of the control ECIV 101 course when Sustainability and Professionalism received an equal number of #1 rankings at the end of the semester with 39% each. Comparing the beginning to the end of the semester in each course, the percentage of students' assigning the highest rank to Sustainability declined in the control ECIV 101 course offerings, from 57% to 39% in Fall 2022 and from 44% to 39% in Fall 2023. Conversely, the percentage of students ranking Sustainability as most valuable in the new Environmental Engineering courses was similar at the beginning and end of the course, with 72% - 73% in the EENV 102 course, and 77% - 78% in the EENV 202 course. This recognition of the high importance of Sustainability, especially for environmental engineering students, may be reflective of this generation of students and may highlight a key difference in motivation for pursuing engineering between civil and environmental engineering students. This finding warrants further study.

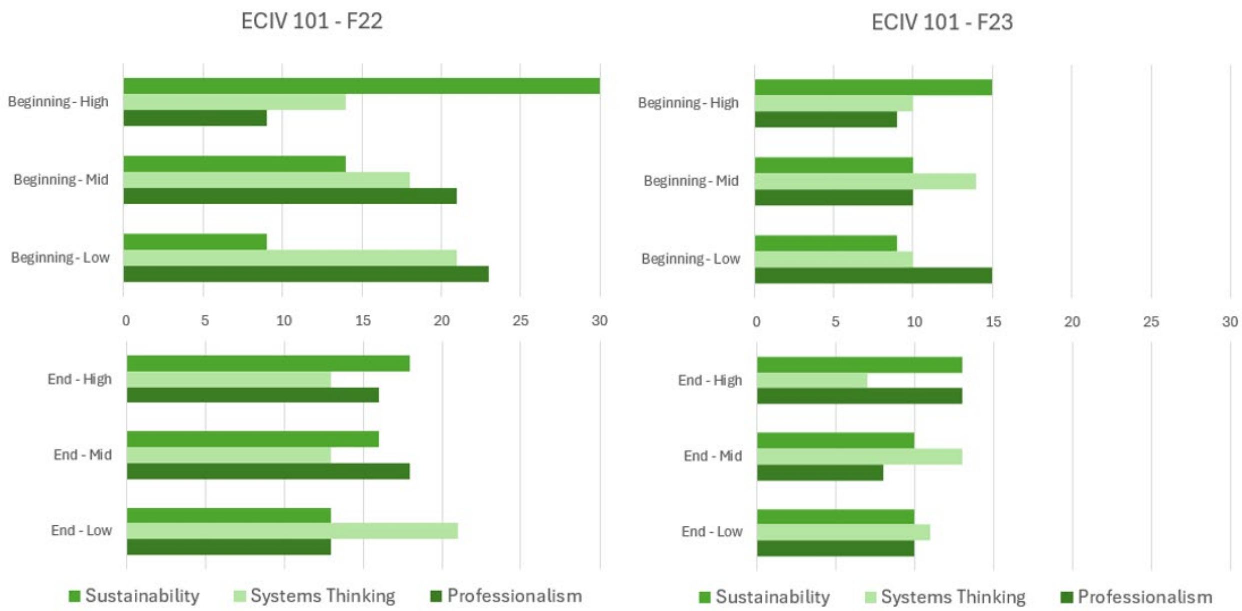

Figure 3. Rankings of EPI pillars by participants in the control ECIV 101 course at the beginning and end of the semester. A high ranking means the student perceived the pillar to hold high value to their chosen field of engineering and conversely for a low ranking. The horizontal axis refers to the number of each rank the EPI pillars received in the survey.

Professionalism was regarded as being of lowest value to both Civil and Environmental Engineering students at the beginning of the semester in all courses. There was considerable agreement among Environmental Engineering students with 69% and 58% of students in EENV 102 and EENV 202, respectively, ranking Professionalism lowest. By contrast, 43% and 44% of students in the control ECIV 101 course offerings ranked professionalism lowest. Students in the new Environmental Engineering courses also regarded Professionalism as being least valuable at the end of the semester with little change in the level of agreement. Students in the control Civil Engineering course ranked Systems Thinking as having the lowest value at the end of the semester in both offerings of the course. The shift among Civil Engineering students may reflect the lack of emphasis on systems thinking in ECIV 101.

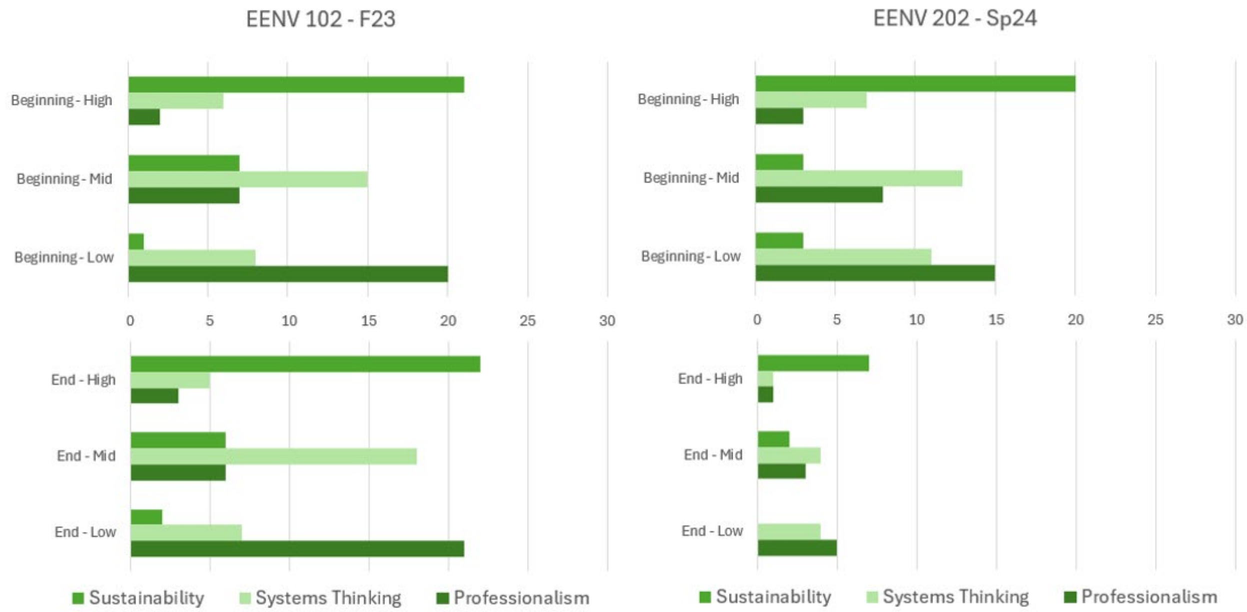

Figure 4. Rankings of EPI pillars by participants in the new RED project-based courses at the beginning and end of the semester. A high ranking means the student perceived the pillar to hold high value to their chosen field of engineering and conversely for a low ranking. The horizontal axis refers to the number of each rank the EPI pillars received in the survey.

4.2 EPI Competencies

For students in the control ECIV 101 course, students' perceptions of EPI competencies that prepare them most and least for being an engineer, technical knowledge and social justice respectively, did not change over time or across the two cohorts. In the following radar graphs, the eight competencies form an array and the concentric rings represent the number of survey respondents designating a given competency as either most valuable (blue) or least valuable (black) to their engineering field at the beginning (dashed) or end (solid) of the semester. Strong consensus looks like a spike and the internal area of the data is small. When there is less agreement between students about what competency is most or least valuable, the internal area of the data increases and the data is distributed around the origin. It is interesting to note that, for ECIV 101 students, there was stronger agreement that social justice does *not* prepare them for engineering than there was that technical knowledge *does* prepare them (Figure 5). As noted previously, ECIV 101 is not designed to integrate socio-technical content and does not address issues which are explicitly related to social justice.

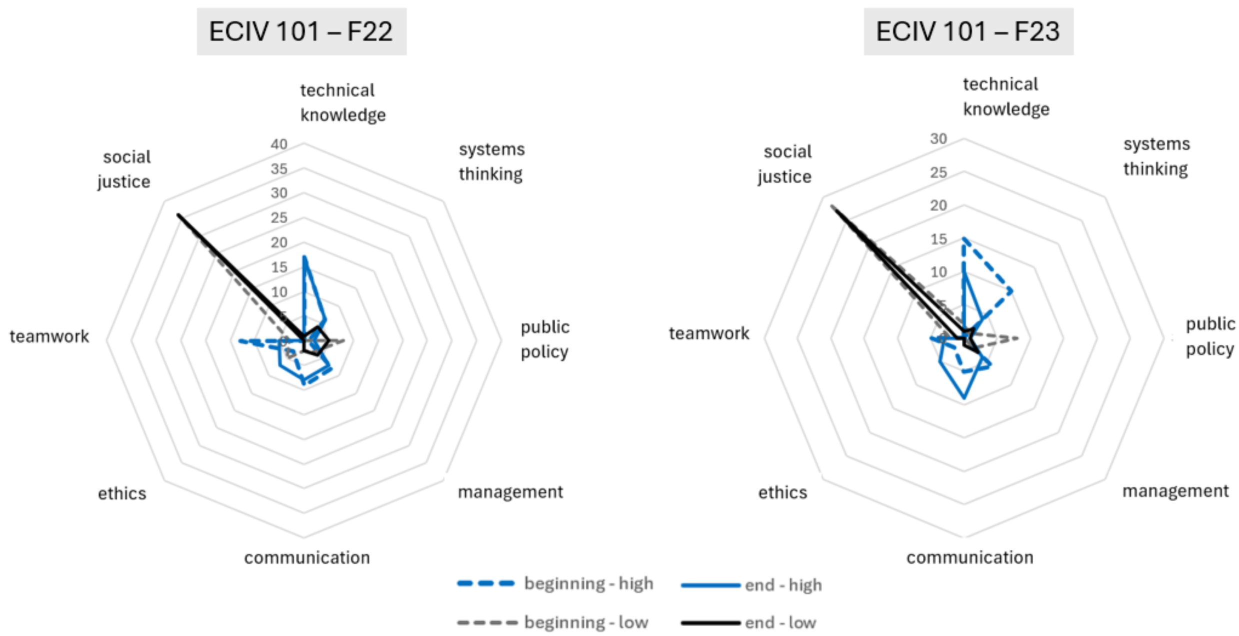

Figure 5. Ranking of EPI competencies by students in the two cohorts of the control course, ECIV 101. Data indicates the number of times each competency received a rank of #1 (high) or #8 (low) in surveys conducted at the beginning and end of the semester. In the Fall 2022 and 2023 offerings, social justice was ranked lowest for importance to the profession at the beginning and the end of the semester (indicated by the large spike for the dotted and solid black lines, which are overlapping on the top left quadrant of the figure) and technical knowledge was ranked highest in importance at the beginning and end of the semester (spike observed around the blue dotted and solid lines, which also are overlapping on the top right quadrant of the figure).

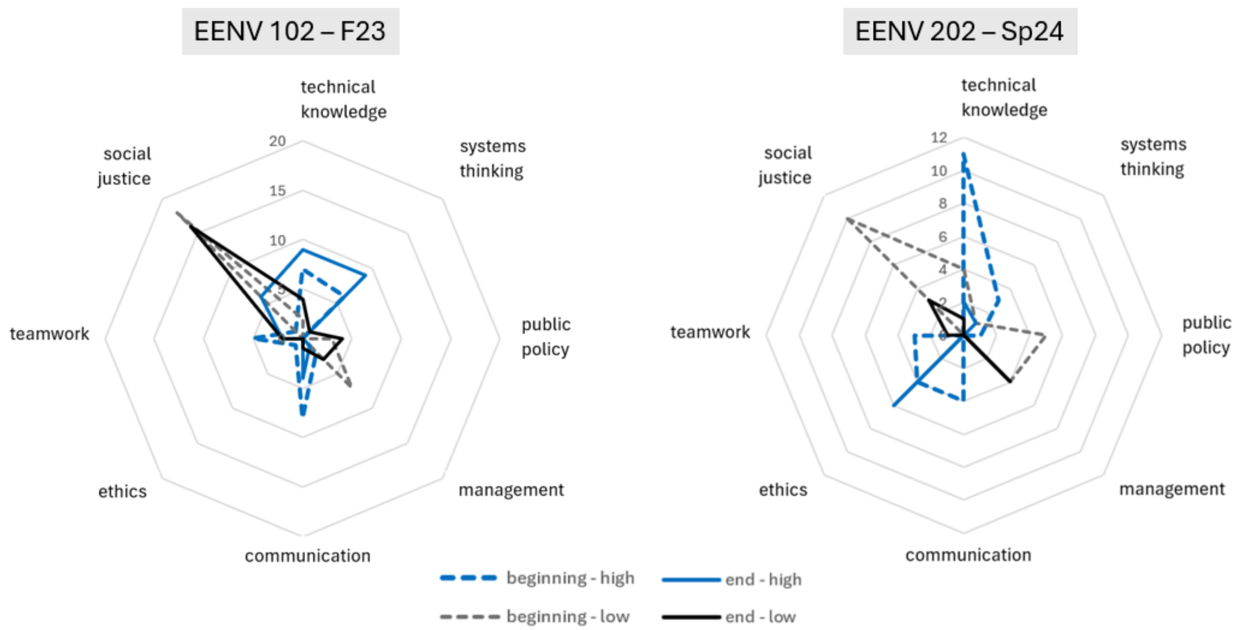

Figure 6. Ranking of EPI competencies by students in the two project-based Environmental Engineering courses, EENV 102 and EENV 202. Data indicates the number of times each competency received a rank of #1 (high) or #8 (low) in surveys conducted at the beginning and end of the semester. In the EENV 102 course (Left), social justice was ranked lowest for importance to the profession at the beginning and the end of the semester (indicated by the large spike for the dotted and solid black lines, which are overlapping on the top left quadrant of the figure). In EENV 102, communication ranked highest at the beginning of the course (blue dotted line pointing straight down), but technical knowledge and systems thinking were ranked highest in importance at the end of the semester (blue solid lines on the top right quadrant of the figure). In EENV 202, at the beginning of the semester technical knowledge ranked highest (blue dotted line pointing straight up) and social justice ranked lowest (grey dotted line in top left quadrant). At the end of the semester the 2nd year course students ranked ethics highest (solid blue line in bottom left quadrant) and management lowest (solid black line in bottom right quadrant).

For Environmental Engineering students, however, there were differences in students' perceptions between the classes and over time (Figure 6). Students in the EENV 102 course reported that communication was the most important engineering competency at the beginning of the semester by a small margin but reported a tie between technical knowledge and systems thinking at the end of the semester. Social justice ranked lowest in EENV 102 at both time points. At the beginning of the semester, students in EENV 202 ranked technical knowledge highest and social justice lowest. By the end of the semester, the students who completed the survey in EENV 202 ranked ethics highest and management lowest. Notably, EENV 202 contained significant course content related to both ethics and social justice, in addition to technical content, and EENV 102 included an introduction to systems thinking. These shifts in rankings observed in the RED project-based courses suggest that these experiential and integrated courses provide additional context and information to students regarding engineering practice and give students opportunities to adjust their perceptions about what it means to be a professional engineer.

5. Conclusion

The survey research presented here was designed to explore how students prioritize the importance of non-technical and multidisciplinary aspects of engineering practice within their conception of engineering as a profession. The research also set out to ascertain whether interventions designed by the RED project team are influencing student conceptions about what it means to be a professional engineer in the 21st century. The RED project aims to disrupt the standard pedagogical pre-occupation with technical content delivery in engineering education by integrating social, economic, ethical, and policy content into project-based courses early on in students' programs of study and emphasizing the interactive aspects of engineering practice (e.g. communication, teamwork). While the team considers all EPI pillars important, the goal is to challenge students' early preconceptions of engineering as a profession by introducing a more holistic introduction to engineering practice.

We observed that the ECIV 101 course survey rankings were much more consistent at the beginning and end of the semester and that course was not designed to integrate socio-technical content like the EENV 102 and 202 courses were designed to cover. We note that in the survey data from the EENV 102 and 202 courses, there were shifts in the students' perceptions of the importance of some of the pillars or technical competencies associated with the profession. These results suggest that the RED project-based courses were more effective than the control course at challenging and building upon students' initial perceptions of engineering values and competencies, and that repeated exposure to integrated project-based courses may enhance this effect.

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