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Infusing Ethics Across the Curriculum in Biological Engineering: Background, Process, and Initial Results

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ABSTRACT

To meet complex ethical challenges in the engineering profession, students need ethics learning experiences that are integrated systematically across the engineering curriculum. Sustaining systematic changes in the engineering curriculum also calls for processes that respect and engage the engineering faculty. This paper reports the work to date of creating a faculty-driven process for infusing ethics across an undergraduate biological engineering curriculum. To illustrate this emerging change process, we report the generation of program level ethics learning objectives, the identification of an ethics course sequence, and the design, implementation, and assessment of an ethics module in a junior engineering biochemistry and microbiology course. Our project to date highlights a number of lessons for enabling a change process for program-wide ethics education in engineering. These lessons include strategies for disrupting existing curriculum patterns and encouraging novel ideas, engaging the faculty adopters of new curriculum, as well as seeking and maintaining leadership and support for ethics education in the discipline.

Key words: Change Strategies, Ethics, Engineering Curriculum, Student Assessment

INTRODUCTION

Most undergraduate engineering programs in the United States have included some form of ethics instruction in their curricula (Colby and Sullivan 2008). Yet, with a few notable exceptions, the ethics contents and learning activities are largely designed at the individual course level, often at the discretion of instructors. To adequately prepare engineering students for complex ethical challenges they will face in the profession, we need to provide ethics learning experiences that are integrated systematically across the engineering curriculum. While literature in engineering ethics and ethics education suggests goals and pedagogical strategies for ethics across the curriculum, achieving sustained ethics learning in engineering programs also requires a transferrable process that can enable and inform holistic changes in curriculum, assessment, and instruction. How then, can educators facilitate changes required in engineering programs to integrate ethics, a subject that is often considered outside the traditional technical core of engineering education, across an undergraduate engineering curriculum? What does it take to promote collective rethinking of ethics education in an entire undergraduate engineering curriculum governed by its faculty members? Seeking answers to these challenges, the authors of this paper participated in a workshop on "Overcoming Challenges to Infusing Ethics into the Development of Engineers" organized by the National Academy of Engineering Center for Engineering Ethics and Society in January 2017. The project we proposed for the workshop was to infuse ethics across an undergraduate biological engineering curriculum at the Pennsylvania State University ("Penn State" hereafter). As education researchers, we also set out to study the process of curriculum development and implementation with the goal of achieving a "model process" for curricular changes, one that can be used for designing and implementing curriculum-wide ethics education in other engineering programs. It is within this context we report this work-in-progress to the greater engineering education community, to share our findings and challenges, and to look for feedback for the improvement of this ongoing initiative.

CONCEPTUAL FRAMEWORKS

Our vision of a program level ethics curriculum has been inspired by the ethics across the curriculum (EAC) movement (Barry and Herkert 2014, Cruz and Frey 2003, Davis 1993, Mitcham and Englehardt, 2016, Riley, Ellis, and Howe 2004). While the EAC literature documents a broad range of accomplishments and pedagogical insights for an integrated ethics curriculum, our effort was particularly informed by Mitcham and Englehardt (2016), who point out that EAC not only provides ethics related activities in multiple courses but also attempts to "interpret, analyze, and assess how their interactions are related and contribute to meeting some common goal or goals" (p. 19). Based on the literature as well as perceived needs in the target engineering program, our work stresses the interaction among ethics education in multiple biological engineering courses and how they collectively help students meet common ethics learning objectives chosen by the program.

Perhaps more importantly, our search for a transferrable process for enabling ethics-related curricular changes in engineering is guided by the literature on adoption of educational innovation

(Borrego and Henderson 2014, Litzinger and Lattuca 2014, Stanford et al. 2016). Borrego and Henderson (2014) summarize four main categories of change strategies in higher education, classified by two variables: changing individual educators versus changing educational environment; and highly prescribed versus emergent changes. The goal of our work, facilitating an engineering program to redesign its ethics education, aligns mostly closely with the fourth category in Borrego and Henderson's (2014) summary: enabling emergent changes in an educational environment. In particular, our work applies a change strategy named "complexity leadership." This complexity leadership theory recognizes that undergraduate engineering education is governed by a complex system, in which leaders can take actions to stimulate collective innovations, but cannot fully prescribe or control the innovative changes (Borrego and Henderson 2014). In such complex systems, leaders stimulate innovations through three key mechanisms: 1) they disrupt existing patterns to make space for new ideas; 2) they encourage novelty and work to further new ideas; and 3) they act as sense makers by creating a common language for the organization to connect with the new ideas (Borrego and Henderson 2014). The proceeding of our project demonstrates these mechanisms: Strategic use of external motivators like accreditation and grant opportunities helped disrupt the previous pattern of ethics education in the program. The project team, consisting of internal and external, and interdisciplinary members, helped encourage novelty. Finally, a consistent process of engaging the biological engineering faculty contributed to shared sense-making, as demonstrated through faculty consensus on program level ethics learning objectives, a progressive curricular sequence, and a shared approach of backward design for ethics education.

PROJECT DEVELOPMENT PROCESS TO DATE

Background

Several biological engineering courses at Penn State had already included ethics related contents. However, the biological engineering faculty members believed that students would benefit from a better coordinated ethics curriculum. Faculty who teach in the program noted that there was unnecessary repetition, a sense that the ethics content of their courses was not well integrated across the entire curriculum, and furthermore, there was no strong evidence suggesting students were appreciating that ethical reasoning is itself a skill that demands a process of maturation and mastery. In 2015, the biological engineering program underwent its latest ABET evaluation, and the evaluators' recommendations created space for revisiting the undergraduate curriculum. With an internal grant from Penn State's Leonhard Center for the Enhancement of Engineering Education, a team of four members—a biological engineering professor, a philosophy professor, the director of the Leonhard Center, and a postdoctoral scholar in engineering ethics—was formed to facilitate review and redesign of ethics education in the biological engineering curriculum. Distributed across several courses, this new ethics curriculum is conceived as a "progressive learning experience" (one that we could also call "scalar learning experience") that provides increasing levels of academic challenges as students progress through it.

Project Overview

This on-going curriculum development consists of five phases: 1) needs analysis; 2) faculty workshops; 3) curriculum design; 4) curriculum implementation; 5) assessment. As of this writing, we have completed the first two phases. Currently we are working on Phases 3 to 5, three consecutive, yet overlapping phases.

Phase 1 was completed in the fall semester of 2016. To ground the new curriculum on biological engineering faculty's educational needs, the project team interviewed nine instructors of biological engineering courses to understand current ethics instruction and perceived needs for improvement (Tang et al 2018).

Phase 2 took place from the fall semester in 2016 to the end of spring semester in 2017. During this phase, the project team engaged the faculty of biological engineering in collaborative curriculum development via three workshops. During the first workshop we explained this project to the biological engineering faculty, presented an overview of ethical frameworks, and engaged them in a discussion of an ethics case study related to genetically engineered corn. During the second workshop, we facilitated the biological engineering faculty to discuss and reach consensus on a list of program level ethics learning objectives (Table 1). During the third workshop, participating faculty members and our project team agreed that a small group of biological engineering faculty members would identify courses for integrating the newly designed ethics curriculum, and instructors of these courses would work with the project team to implement and assess the new curriculum. Details of our faculty engagement process, including the mechanisms used to build faculty consensus on

Table 1. Ethics Learning Objectives for the Biological Engineering Program.

1. Define ethics and engineering ethics.
2. Give examples of ethical values.
3. Interpret key elements of engineering codes of ethics, such as "conflict of interest."
4. Explain why it is important for Biological Engineers to act ethically.
5. Act according to ethical principles in a professional context.
6. Give examples of ethical issues related to Biological Engineering and explain why the issues are ethical issues.
7. Articulate ethical responsibilities when working in a team.
8. Analyze the professional and broad societal context for ethical decisions.
9. Evaluate the ethical implications of capstone project.
10. Provide ethical leadership within a team.
11. Include cultural considerations in ethical analysis.

Table 2. The "Ethics Spine" in the Redesigned Biological Engineering Curriculum.

Course Name	Time in the Curriculum
Engineering Elements of Biochemistry and Microbiology	Fall semester Year 3
Contextual Integration of Communication Skills for the Technical Workplace	Spring semester Year 3
Contextual Integration of Leadership Skills for the Technical Workplace	Fall semester Year 4
Biological Engineering Design I	Fall semester Year 4
Biological Engineering Design II	Spring semester Year 4

program level ethics learning objectives, are reported in an earlier publication (Tang et al 2018). It is worth noting that the generation of program level ethics learning objectives provided a common language for the project team as well as the biological engineering faculty to understand and communicate the ethics education initiative. These shared learning objectives also provide a guideline for instructors to align course level learning objectives, assessment, and instructional activities.

Phase 3 began in the summer of 2017. A small group of biological engineering faculty members met regularly over the summer to review the undergraduate curriculum and to create a plan for integrating ethics. This working group was charged to identify a curriculum path that allows for meeting of program level ethics learning objectives while progressively developing students' moral literacy, proceeding from foundational ethical concepts to responsible professional practice (Tuana 2014). The small group work resulted in an "ethics spine" in the biological engineering curriculum—a cluster of five courses that form a progressive ethics learning experience (Table 2). While we continue to encourage other course instructors to integrate ethics contents related to their courses, the project team is working closely with instructors of the courses designated in the ethics spine to design and align the content, assessment, and instruction of ethics components. An important feature of designing the new ethics curriculum is the application of the backward design process, which systematically aligns learning objectives, assessment, and instructional plans (Wiggins and McTighe 2005). The following section illustrates this philosophy with the design and delivery of an ethics module in a junior level biological engineering course.

DESIGN, DELIVERY, AND ASSESSMENT OF AN ETHICS MODULE

The biological engineering faculty working group chose the course Engineering Elements of Biochemistry and Microbiology to begin the "ethics spine" since all students in the major are required to take this course and it contains subject matter suited for ethical analysis. Subsequently, the project team developed learning objectives, assignments, an instruction plan, and in-class activities for an ethics module, which was recently implemented in this course.

Table 3. Ethics Learning Objectives in Engineering Elements of Biochemistry and Microbiology.

1. Define ethics.
2. Practice ethical thinking as a reflective activity.
3. Exercise ethical thinking through the lens of a professional code of ethics.
4. Explain why it is important for Biological Engineering students to act ethically as individuals, employees, researchers, teachers, and professionals.
5. Develop and exercise the ability to identify and analyze ethical issues associated with Biological Engineering using different ethical frameworks and to develop a recommended plan of action considering global, economic, environmental, and societal issues.

Ethics Learning Objectives

To lay a foundation for students' continued growth in moral literacy (Tuana 2014), we chose to focus on a subset of the program level ethics learning objectives in this module. We also reframed these learning objectives based on the context of the course (Table 3).

Instruction Plan

The ethics module in Engineering Elements of Biochemistry and Microbiology consists of a partial class period (20 min), a full class period (50 minutes), and a full lab session (110 minutes). For the first implementation, a member from our project team (who is also a biological engineering professor) led the classes and lab as a guest instructor. The first short class period provided an overview of the experience, its objectives, and the motivations behind the module's design. In the second class, the guest instructor guided students to examine reasons for being ethical engineers and individuals, introduced the American Society of Agricultural and Biological Engineers Code of Ethics, and engaged students in a discussion activity. For the discussion students reflected on and shared a disagreement on matters of right and wrong they had had with someone who they respect. After recalling the experience, students discussed the disagreement with classmates and were asked to identify the values in conflict and how they now viewed the disagreement after the reflection and discussion. Before the lab session, students were assigned to watch a short video entitled "The Arc of Ethical Action." This video features another project team member (a professor of philosophy) explaining three foundational ethical frameworks: character-based, rule-based, and consequence-based. During the lab, the guest instructor introduced a seven-step process for ethical decision making (Figure 1), modified from a twelve-step process that was developed by Penn State's Rock Ethics Institute (Tuana and Vasco n.d.). Students spent the rest of the lab working individually at first, and then in groups, to analyze an ethical case study about genetically engineered pigs as organ donors for humans.[1]

[1] The video can be accessed at https://sites.psu.edu/ethicalaction/. The case study, assignments, and rubrics are available upon request.

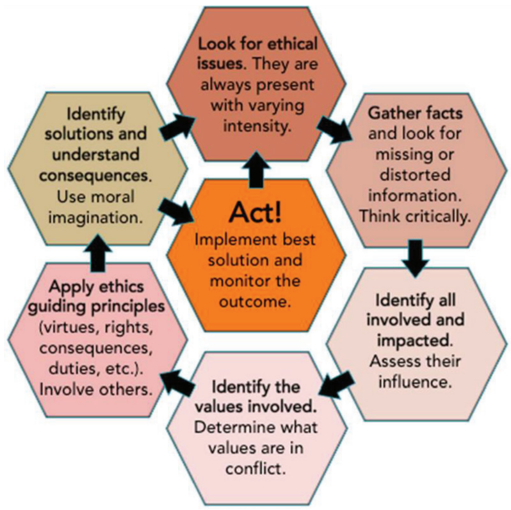

Figure 1. The Ethical Decision Making Process.

Assessment

Given that we offered the newly designed ethics module for the first time, the assessment focused not on drawing statistically significant conclusions but on gathering feedback for continuous improvement of the module, including its assessment mechanism. We assessed students' beliefs and ethics learning through a combination of direct and indirect assessment, in the form of surveys, quizzes, and written analyses of the case study. Students shared their levels of agreement with three statements about the relation between ethics and biological engineering in pre- and post- module surveys. The survey results are presented in Table 4. We received 49 responses to the pre-module survey and 35 responses to the post-module

Table 4. Student survey response before and after module.

Survey Statement		It is important for biological engineers to understand ethics.	It is important for biological engineers to act ethically in their professional practice.	Biological engineering is a field that involves numerous ethical challenges.
Pre-Module	**Total response**	49	49	49
	Mean*	9.39	9.69	8.88
	SD	1.03	0.71	1.93
Post-Module	**Total response**	35	35	35
	Mean*	9.80	9.89	9.86
	SD	0.47	0.40	0.35

*The survey was based on a Likert scale of 0 to 10, with 0 indicating "strongly disagree" and 10 indicating "strongly agree."

Table 5. Student Answer to Quiz Question 5.

		Exemplar	Satisfy	Margin	Unsatisfy	Total
Pre-Module	**Answers**	2	3	7	37	49
	Percentage	4.08	6.12	14.29	75.51	100
Post-Module	**Answers**	8	7	13	7	35
	Percentage	22.86	20.00	37.14	20.00	100

survey.[2] On average, students' agreement with all three statements increased after completing the ethics module, and the biggest increase happened with the statement that "Biological engineering is a field that involves numerous ethical challenges."

We also assigned six quiz questions to students before and after the module. In particular, quiz question 5 ("Are you familiar with any formal process for ethical decision-making? If so, please describe it?") was included to assess students' familiarity with formal ethical reasoning processes. A project team member assessed student answers according to rubrics developed by the project team. The results are presented in Table 5. Student answers to quiz question 5 show that the majority of students (75.51%) were not able to identify any steps for a formal ethical reasoning process prior to the delivery of the ethics module. In comparison, 80% of students who submitted their quiz answers after the module were able to recall some or all key steps in an ethical reasoning process.

Furthermore, students' ability to apply the ethical reasoning process is assessed through written analysis of the ethics case study. To structure the analysis, we provided students with a worksheet that includes seven questions (Table 6). Among them, questions 1, 2, and 5 respectively ask students

Table 6. Questions for Ethics Case Analysis.

1) What are the ethical issues in the case?
2) Who and what are the relevant stakeholders, facts, and values? What values are in conflict?
3) What are the relevant consequences, virtues, and duties involved in this case?
4) List one ethical issue associated with this case that involves the following:
    (a) Has a global impact
    (b) Has an economic impact
    (c) Impacts the environment
    (d) Impacts our society
5) What are the possible and optimal actions and the associated consequences? Do you support continuing this research?
6) How does your solution address the issues you identified in question 4 a-d?
7) How can the ethical issues in this case be avoided in the future?

[2] Considering its piloting nature, we did not offer the assessment as graded assignments, which might have an impact on the completion rate of the post-survey.

Table 7. Student response to ethical case analysis.

		Exemplar	Satisfy	Margin	Unsatisfy	Total
Q1	**Answers**	14	26	7	0	47
	Percentage	29.79	55.32	14.89	0.00	100
Q2	**Answers**	9	10	28	0	47
	Percentage	19.15	21.28	59.57	0.00	100
Q5	**Answers**	7	26	11	3	47
	Percentage	14.89	55.32	23.40	6.38	100

to identify the ethical issues; identify relevant stakeholders, facts, and values; and to formulate possible and optimal actions. A project team member assessed student responses using rubrics created by the project team. The results of student scores to questions 1, 2, and 5 are summarized in Table 7.

Student scores on the case analysis show that over 85% of the students were able to identify complex ethical issues in a case related to biological engineering (Q1), and over 70% were able to generate justifiable actions facing an ethical challenge (Q5), yet the majority of students (59.57%) struggled with articulating the ethical values involved in the case (Q2). The results in Table 5 and Table 7 suggest that students began to identify and apply an ethical reasoning process in analyzing ethical challenges, while most of them were not yet proficient in using formal ethics language to describe their analyses.

SUMMARY AND CONCLUSIONS

Taking a faculty-driven approach to educational design, the project team has worked closely with the biological engineering faculty to develop program level ethics learning objectives and to design and implement related learning experience in a core biological engineering course. The project to date demonstrates the provisional success of utilizing a complexity leadership process for inducing innovation in educational organizations: We used ABET evaluation and a grant from the university engineering education center as strategic opportunities to disrupt existing patterns of ethics education in the biological engineering program. An interdisciplinary project team, consisting of members internal and external to biological engineering, helps bring novel perspectives and expertise to the curriculum initiative. Finally, consistent engagement with biological engineering faculty using interviews and workshops contributed to collective sense making of the new curriculum initiative. Our process also shares several attributes with change processes recommended in the STEM education literature (Borrego and Henderson 2014, Froyd et al. 2000). In addition, we hope to make clear that effective use of the complex leadership strategy requires, in the first place, strong leadership in the organization targeted for change. This has been the case with our project in the biological engineering program. One of the biological engineering faculty members, who is also a project team member, provided crucial internal advocacy for the curriculum change. The department head of agricultural and biological engineering, in which the biological engineering program is housed, also demonstrated commitment to this initiative and provided necessary administrative support.

Given the time and resources available, the project team did not explicitly collect student inputs on the ethics curriculum. We chose to prioritize faculty insights in the current curriculum development process. Nevertheless, we recognize the importance of student perspectives, particularly perspectives on their learning needs. Thus, we plan to integrate student feedback into revisions of the curriculum. Successfully meeting our project objectives also requires continued faculty development. Through our interactive workshops with the biological engineering faculty, including pedagogical demonstration of ethics case analysis and conversations about ethical frameworks, we have helped increase the biological engineering colleagues' level of *comfort* with integrating ethics into core technical courses. This perceptual change has been instrumental in building consensus on program level ethics learning objectives and the corresponding curriculum path. The following challenge is to prepare more biological engineering faculty members to be *confident* in teaching ethics in their technical courses. Moving forward, we will work with the instructors of two professional development courses and the capstone courses in the biological engineering program to redesign and align the ethics components in light of the program level ethics learning objectives. We will also work with biological engineering instructors to develop, deploy, and refine processes for assessing student learning of ethics.

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