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Overcoming Challenges to Enhance a First Year Engineering Ethics Curriculum

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ABSTRACT

A review of the First Year Engineering course sequence at Virginia Tech characterized the current state of ethics education in the program, and informed a strategy to enhance the ethical development of first-year engineering students. This paper reports the results of our initial review of the curriculum, our improvement plan, assessment of our initial implementation, and reflections on overcoming challenges to improving student learning of engineering ethics. Structural changes to class size and number of sections are improving the consistency of ethics instruction, while a curriculum refresh led to a deeper incorporation of ethics frameworks in case analysis and critical reflection as the instructional norm. While opportunities were structurally limited by curricular constraints, the project was designed to fit within these and strengthen this small corner of the curriculum.

Key words: change management; moral development; curricular reform; first-year engineering

INTRODUCTION

As part of a National Academy of Engineering (NAE) project on Overcoming Challenges to Infusing Ethics in the Engineering Curriculum, our team undertook a review of the First Year

Engineering course sequence at Virginia Tech (ENGE 1215 and 1216) in order to determine the current state of ethics education in the program and to chart a path towards improving the ethical development of first-year engineering students. This work-in-progress reports the results of our initial review of the curriculum, our improvement plan, initial findings, and reflections on the challenges we faced.

Donna Riley oversaw the project, with graduate students including Andrew Katz carrying out the detailed analysis of the existing courses. A report summarizing the analysis and suggesting specific course revisions was delivered to Ken Reid, who worked with Natalie Van Tyne to further develop, implement, and assess the changes. The initial project also conceived of a more revolutionary elective course on engineering, for, by, and with communities in partnership with Yanna Lambrinidou, but Riley's and Katz's departure from Virginia Tech interrupted those plans.

ENGE 1215 and 1216 are a two-course introductory sequence of two credits each, taken by all incoming engineering students at Virginia Tech (over 2000 students). In an overcrowded engineering curriculum, all fourteen engineering majors at Virginia Tech rely to some extent on the First Year Engineering course sequence to lay a foundation for a broad set of engineering technical and professional competencies, including ethics. Because this is engineering students' initial exposure to the profession, our goal is a properly sequenced introduction to engineering ethics across both courses. However, achieving and maintaining this foundational introduction to engineering ethics within the constraints of two two-credit courses that already cover a great deal of content that competes for student attention is a major challenge.

Indeed, while much progress has been made over the past several decades in developing learning outcomes, content and pedagogy for engineering ethics education, it is the structural barriers that continue to present challenges. Ethics is relegated to the first year and capstone, spaces that are already overcrowded, because they are viewed as add-ons rather than a core competency of the profession. Instruction relies on a small number of passionate faculty, and development of core faculty in ethics remains an exception rather than the norm. While the ideal remains a spiral curriculum in which students develop ethics over four years, we are far from a time when this is the standard for all engineering majors.

Ethics must remain part of first year engineering because it is the place where engineering identity develops, when students learn engineering is a profession that entails certain commitments and responsibilities. We lay this groundwork while navigating the complexities of academic freedom and faculty governance in a large institution, awaiting an opening to put forward an overall framework for engineering ethics education that might be adopted college-wide.

SUPPORTING LITERATURE

The team reviewed the state of the art for engineering ethics pedagogy and curriculum; the current community consensus is perhaps best encapsulated in the *Cambridge Handbook of Engineering Education Research* (Barry and Herkert 2014) and a recent systematic literature review (Hess and Fore 2017). The team sought to lay a flexible foundation for any of the College's fourteen engineering majors to build upon, ideally using a sequenced, spiral, or ethics-across-curriculum approach (Bruner 2014; Harden and Stamper 1999; Riley, Ellis, and Howe 2004). Such approaches are consistent with what is known about student moral development and ethical identity growing (nonlinearly) through sustained encounters over time (King and Kitchener 1994; Kohlberg and Hersh 1977).

The complex sociotechnical nature of today's grand challenges requires engineers to have the capacity to recognize and reflect critically upon ethical situations, analyze them by applying multiple frameworks (e.g., utilitarian, deontological, virtue ethics, etc.), generate creative courses of action, and make deliberate, thoughtful decisions. ABET's learning outcomes (ABET 2018) thus require an explicit focus on ethics. While ABET does not provide specifics, established norms as reflected in recognized exemplars (NAE 2016), literature reviews (Haws 2001; Hess and Fore 2017), and commonly used textbooks (Harris, Pritchard, Rabins, James, and Englehardt 2013; Martin and Schinzinger 2005; Vesilind and Gunn 1998; Whitbeck 2011) go beyond cursory exposures such as awareness of professional codes and rule following, favoring critical reflection and analytic capacities using formal ethical frameworks and, in some cases, meta-ethics (Haws 2004). It should be noted that the phrase "ethical reasoning" is often used broadly to refer to aspects beyond reasoning skills, including contextual and affective elements such as ethical self-identity development (AAC&U 2009).

Capacities in ethics are not only the purview of professional engineers but are also sought after in all college graduates (AAC&U 2009). Engineering educators cannot leave ethical instruction to general education, however; the particular professional responsibilities of engineers form a critical context in which our students must form their ethical skills, dispositions, and behaviors (Claris and Riley 2012). It is through opportunities for praxis that fully integrate theory and application that engineers learn critical thinking and reflective action. King and Kitchener's (1994) research indicates that ethical identity develops through regularly and consistently offering growth opportunities that challenge students to deepen their capacities for reflective judgment; the traditional age and developmental level of typical first-year students is a particularly fruitful place to offer such challenges as students gradually move from relying on authoritarian epistemologies toward more complex ways of knowing.

INNOVATION

The first step in our plan was to review ethics education in ENGE 1215 and 1216, which the team undertook in spring 2017. Despite ethics being mentioned in both course descriptions, neither course consistently included some of the most fundamental ethics content commonly expected in engineering ethics curricula (Barry and Herkert 2014).

The course description of ENGE 1215 includes: “data collection and analysis, engineering problem-solving, mathematical modeling, contemporary software tools, professional practices and expectations (e.g. communication, teamwork, **ethics**), and the diversity of fields and majors within engineering.” [emphasis added] Although ethics is a part of the course description, it is not a stand-alone objective but rather treated as part of a group of professional skills gained in the course. This matters because you can’t change what you don’t measure (Riley 2016; Shuman, Besterfield-Sacre, and McGourty 2005).

The limited emphasis on ethics in ENGE 1215 was a missed opportunity for sequencing ethics learning in the program so that students “learn and relearn” ethics (Bruner 2014; Harden and Stamper 1999). The baseline curriculum in ENGE 1215 covered the difference between ethics and morality, and students read professional ethics codes. Assessment ranged from exam questions based on professional codes of ethics to the incorporation of ‘ethical considerations’ within a design report. Notably missing from most sections of the course were formal ethics frameworks and their application to common engineering ethics cases using explicit ethical reasoning, and there was little to no opportunity for students to develop their abilities in critical reflection in the context of engineering practice.

In ENGE 1216, ethics is explicitly mentioned in a stand-alone course learning objective: “Evaluate ethical implications of engineering solutions.” To achieve this objective, there were two days that contained material related to engineering ethics, typically near the midpoint and end of the semester. The ethics content was interspersed with other course content, primarily related to MATLAB. Students reviewed specific canons in professional codes of ethics and engaged in class discussion or a role-playing exercise around an engineering ethics case study (https://www.scu.edu/ethics/focus-areas/more/engineering-ethics/engineering-ethics-cases/occidental-engineering-case-study-part-1/).

Later in the semester the class revisited engineering ethics in the workplace including topics such as bribery, whistleblowing, and confidentiality. One accompanying homework assignment asked students to reflect on a case study from the 2003 energy blackout in the northeastern United States. To guide their two-page response, students were asked whether the utility should have been fined, making a comparison to the Exxon Valdez oil spill. Students were then asked to identify "ethical dilemmas" (a problematic term suggesting only two options) that preceded the blackout. Students were not asked to apply formal ethical frameworks in this assignment, but were encouraged to reference the ABET code of ethics in constructing their responses.

The team took a pragmatic approach to improving the course, recognizing the limited time available with numerous competing learning objectives, and the large size of the teaching team for the course. While some members of the team might seek a broader or more critical frame for engineering ethics curriculum and pedagogy, the recommendations focused on what was practical and achievable to improve ethics learning in the short term:

Recommendation 1

Incorporate Ethical Reasoning in both ENGE 1215 and ENGE 1216 by teaching ethics frameworks, professional codes, and their applications in ENGE 1215, and build on this knowledge toward deeper ethical reflection in the context of engineering design in ENGE 1216. ENGE 1215 should adopt an explicit and clear learning goal aligned to ethical reasoning including moral frameworks of virtue ethics, utilitarianism, consequentialism, and the engineering code of ethics so that in ENGE 1216 students can revisit knowledge learned in 1215 and develop greater understanding of ethical responsibilities and impacts related to professional engineering practices.

Recommendation 2

Draw on existing case study banks to select case studies to adopt or adapt for use in both ENGE 1215 and ENGE 1216. An agential case study format (Whitbeck 1995) positions students as actors rather than bystanders or judges. It allows students to articulate their facility with multiple approaches to ethical reasoning and understandings of ethical responsibilities of professional engineering practice over the course of the program and thus can be used as a summative assessment tool (Wiggins and McTighe 1998). The team suggested promising case studies for each course from existing case study banks:

- ENGE 1215: Energy Transitions - http://www.onlineethics.org/Topics/Enviro/Energy/39660.aspx
- ENGE 1216: Power behind the drone - http://ethics.iit.edu/eelibrary/biblio/power-behind-drone

Recommendation 3

Utilize the AAC&U (2009) Ethical Reasoning VALUE Rubric (with modifications) to assess student achievement of ethics learning goals in both courses, aligning with the ethical reasoning learning indicator in Virginia Tech's new general education curriculum. https://www.aacu.org/ethical-reasoning-value-rubric

Recommendation 4

In the longer term, the learning goals of ENGE 1215 should be revisited in order to make ethics explicit, and to name ethical reasoning and an understanding of professional responsibility as two key learning outcomes. The learning goals of ENGE 1216 should be similarly edited to address an increased role of application of ethical reasoning and reflection to the design process and to real-world complex problems.

At this point the project experienced a major disruption with two team members (Riley and Katz) departing for another institution. The team documented its activities up to that point through a written report, which informed continued action on the recommendations.

IMPLEMENTATION

ENGE 1215 was modified in fall 2018 to a course presented in three modules: Engineering Opportunities, Modeling Engineering Solutions and Unpacking Problems. The course content now includes intentional use of case studies with guides to in-class discussion on ethical considerations and unintended consequences. Students are to include a discussion of ethics as part of a larger project typically focused on the Engineering Grand Challenges (http://www.engineeringchallenges.org/). A pilot instructor training included an orientation to ethical frameworks, with course material provided to help scaffold discussion. Impacts of these changes are yet to be assessed and further developed.

In ENGE 1216, the team has piloted and begun assessment for a first round of changes. The engineering ethics unit in Van Tyne's sections of ENGE 1216 was expanded during the fall 2017, spring 2018 and fall 2018 semesters with a briefing about ethical frameworks, class discussion of a case study, and an individual homework assignment using a different case study and the application of the ethical frameworks covered in class. Students were asked to determine an outcome for the case and justify it using reference sources as well as the ethical frameworks.

ASSESSMENT

As ENGE 1215 and 1216 are multi-section courses linked in a two-course sequence that together form a first year program, the team felt it was important to design tools for the assessment of student learning that could be administered across both courses to gauge students' growth in ethical reasoning and articulation of understanding of ethical responsibilities in professional engineering practice. This assessment would also give us valuable feedback on the impacts of our interventions to enhance the engineering ethics curriculum. The team noted that portfolios could be used as powerful tools for measuring multiple learning outcomes across the program over time (Shuman,

Table 1. Recommended Assessment Matrix for Foundations of Engineering I & II and Alignment with ABET. (following Olds and Miller 1998)

Program Objectives	Performance Criteria	Implementation Strategy	Assessment Method	Timeline	Feedback
Foundations of Engineering will teach students to:	How will you know the objective has been met? What level of performance meets each objective?	How will the objectives be met? What program activities help you meet each objective?	What assessment methods will you use?	When will you measure?	Who needs to know the results? How can you convince them the objectives were met? How can you improve the program and assessment process?
Apply relevant ethics frameworks to engineering responsibilities and holistic impacts	80% of students in ENGE will be rated at 1 (milestone) or 2 (benchmark) for ethical reasoning using relevant ethics frameworks (see AAC&U 2009)	Students will apply frameworks of virtue ethics, consequentialism, and deontology to understand engineering professional and ethical responsibility.	Rubrics, course evaluation data, course surveys, and other methods deemed appropriate by the assessment committee.	Each semester and each year	Assessment Committee; Department and College Undergrad Curriculum Committee; Advisory Board; Associate Dean for Undergraduate Affairs Feed into ABET and Department review processes
Develop an ability to articulate ethical reasoning related to professional engineering practice	80% of students in ENGE will be rated at 3 (milestone) or 4 (benchmark) for ethical reasoning using relevant ethics frameworks.	Students will develop ethical reasoning related to professional engineering, supported by previous knowledge and experience in engineering practice.	Rubrics, course evaluation data, course surveys, and other methods deemed appropriate by the assessment committee.	Each semester and each year	Assessment Committee; Department and College Undergrad Curriculum Committee; Advisory Board; Associate Dean for Undergraduate Affairs Feed into ABET and Department review processes

Besterfield-Sacre, and McGourty 2005), using common rubrics to measure achievement of learning outcomes across assignments that may vary across sections, affording some instructor autonomy and manageability for grading teams across large class sizes.

The team developed an assessment strategy (Table 1) with program-level learning goals specifically aligned to student ethical reasoning and understanding of professional responsibility. Students would demonstrate their abilities in ethical decision-making by articulating reasoning that encompasses holistic issues and the application of moral frameworks and learning experiences in professional engineering practice (Hoey and Nault 2008). Formative feedback would allow for improvement by both students and instructors during a given semester. Assessment data would also be used as summative feedback to identify opportunities for course and program improvement (Miller and Leskes 2005) and to improve alignment among ABET Criterion 3, course objectives, and Virginia Tech's General Education Learning Indicators for Ethical Reasoning.

This assessment plan has not yet been implemented, as the team has focused on the initial rollouts of recommended curricular changes. Preliminary data from rollout in ENGE 1216 are given in Table 2,

Table 2. Ethical Frameworks Homework Assignments in Selected Sections of ENGE 1216.

Description	*Fall 2017*	*Spring 2018*	*Fall 2018*
Students	90	120	134
Case Study	Occidental Engineering	Scientific Testing on Animals	Scientific Testing on Animals
Ethical Frameworks	Deontology Virtue Ethics Utilitarianism Consequentialism	Deontology Virtue Ethics Utilitarianism Contractarianism	Deontology Virtue Ethics Utilitarianism
Grading Criteria	Decision supported by rational evidence	Decision supported by rational evidence	Decision supported by rational evidence
	At least three stakeholders identified	At least two different reference sources are cited	At least two different reference sources are cited
	Effect of decision is stated clearly for each stakeholder	Reference sources are listed at the end in IEEE format	Reference sources are listed at the end in IEEE format
Average Grade	87.5%	76%	77.5%

including a summary of the number of students, case studies and ethical frameworks taught, grading criteria, and average grade for each of the three semesters. Note that the removal of reference to "stakeholders" corresponds to the change in case study employed, while the addition of IEEE referencing to the rubric was not a direct substitution but a separately needed accountability for information literacy.

Ethical frameworks were applied to instruction for approximately 13% of all students in Spring 2018, and for approximately 50% of all students in both Fall semesters (fall semesters have a lower overall enrolment for this course). The lower average grades for the spring 2018 and fall 2018 semesters can be attributed to two more specific grading criteria that certain students disregarded when they completed the assignment, rather than a lack of understanding of the given frameworks. The final grading criterion was changed between Fall 2017 and Spring 2018 when a different case study was implemented, when the assignment's objectives were modified to emphasize ethical arguments based on evidence rather than stakeholder views. Further analysis of student work is planned for the future, implementing the assessment rubric described above to examine students' ethical development over both courses and iterating curriculum and pedagogy to optimize attainable gains in the available time.

REFLECTION ON OVERCOMING OBSTACLES

The departure of core members of the initial team (Riley and Katz) in summer 2017 presented an obstacle to continuing the project as originally proposed. While both Reid and Van Tyne stepped in where Riley and Katz left off, there were points of discontinuity. The recommendations in the report were adjusted throughout implementation based primarily on feasibility considerations. This would normally be the case in implementation of any innovation, but may have been more pronounced here due to the departure of team members and a related change in departmental leadership. The `bench depth' of faculty dedicated to moving ethics education forward at Virginia Tech was a major factor in overcoming this obstacle.

The highly distributed nature of the First Year Engineering courses, taught in roughly 70 sections of 30 students each by a team of around two dozen instructors, made it difficult to ensure consistency of instruction across sections. A shift is underway now to 72-student sections, which will enable a smaller instructional team to work more closely together. Adoption of large-class pedagogical best practices for discussion and other active learning approaches will enable student learning to continue in a similar fashion (Hornsby, Osman, and De Matos-Ala 2013; MacGregor, Cooper, Smith, and Robinson 2000; Pollock, Hamann, and Wilson 2011). The biggest obstacle to making this change was available classroom infrastructure, and the recent addition of new classroom space made this shift possible. This may be the single biggest step in overcoming obstacles to innovation, for ethics and other topic areas.

The structure of Virginia Tech's curriculum was a significant obstacle (known from the outset). There is a fatal flaw in the small number of credits allocated to first year instruction in engineering, with an impossible task of covering in four credit hours all the professional competencies as well as instruction in problem solving, design, and MATLAB coding. Instructors and students do their best, investing well beyond what is reflected in the credit-hours allocated. Attention to engineering ethics in this environment is partial at best, and the chosen strategy of being realistic about what can be achieved reflects back accurately to accreditors, the engineering education community, and the profession, their expressed priorities. At the same time, Virginia Tech made a significant institutional investment in ethics education for all students through an ethics learning indicator in general education. By aligning the introductory engineering courses to this new learning indicator, there is additional accountability for taking ethics education seriously within engineering.

At the department level, ethics instruction is not consistently valued by all instructors, because each comes with a different set of assumptions about what and how students should learn. The team has been addressing this through training, sharing course materials and instructional practices. Focused professional development opportunities in engineering ethics could further enhance instructor capacities and commitment for teaching engineering ethics.

Assessment was difficult to implement due to resource constraints of personnel time and the considerable assessment load already imposed by both regional and disciplinary accreditation. Any focused assessments of engineering ethics must be built into existing feedback systems in order to be implementable and effective.

SUMMARY AND CONCLUSION

The experience of stepping back and evaluating our efforts in first year engineering ethics education in order to innovate was a crucial exercise in self-accountability. It afforded the team an opportunity to reflect, focusing on an aspect of the curriculum that has long been under-attended in many engineering programs. There were points in the course where ethics education had inadvertently eroded over time, and there was now an opportunity to shore those up. There were also new opportunities to advance or enhance student learning with improved assignments and course coordination. The two biggest shifts were the structural changes that improved consistency in ethics instruction across sections, and the move from a more cursory awareness of ethics codes to a deeper incorporation of ethics frameworks in case analysis. While opportunities were structurally limited by our curricular constraints, the project was designed to fit within these and make this small corner of the curriculum as strong as it can be. There is more work yet to be done, including assessment and further development of assignments and instructor training, and integration of ethics with student course projects. This intervention and related activities has so far served to renew these efforts in the department, and rekindle hope for overcoming obstacles in engineering ethics education at Virginia Tech.

Our community has over generations built an engineering ethics education system that continues to run up against familiar obstacles that are baked into the structure of undergraduate engineering education. While we were able to make significant improvements without butting up against these constraints, and these sorts of opportunities likely abound in many colleges of engineering, we must also persistently seek opportunities to address the underlying structural issues that will enable us to ultimately move engineering ethics to the core of engineering education.

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