Integrating Ethics in Engineering Education through Multidisciplinary Synthesis, Collaboration, and Reflective Portfolios

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ABSTRACT

This article discusses two multidisciplinary courses created at the Colorado School of Mines that were developed to integrate ethics into the first-year engineering curriculum: "Nature and Human Values" (NHV) and "Innovation and Discovery in Engineering, Arts, and Sciences" (IDEAS). In both NHV and IDEAS, our objectives are to meaningfully integrate personal and professional ethics within a larger context of integrating humanities and social sciences with engineering curricula. We teach students how to apply ethical reasoning in support of engineering solutions through user empathy, problem definition, stakeholder engagement, communication of outcomes, and analysis of contexts and impacts. In the process, we emphasize personal morals, professional ethics, and environmental ethics via literary readings and case studies that have a strong central narrative of engineering and / or environmental impacts. Students practice close reading and analysis, communication in many rhetorical modes, and evaluation of and reflection about the wider contexts and effects of design solutions. These practices, as well as course assessments, enable a focus on synthesis across learning outcomes. Collaboration between faculty from many disciplinary areas as well as student teamwork and group projects also supports this synthesis, and reflective portfolios encourage students to explore their ideas at different learning stages and to review their own perceptions and decisions over time. Our overall theory of change is to simultaneously infuse engineering problem solving with values-sensitive analysis and design, requiring communication skills and ethical reasoning at every step.

Key words: Multidisciplinary, Reflection, Honors programs

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INTRODUCTION

The Colorado School of Mines (Mines) has a long history in trying to overcome the challenges of integrating ethics into its engineering curriculum beginning over 20 years ago. The course "Nature and Human Values" (NHV) was developed in 1997 when faculty across campus realized that Mines graduates were lacking in two key areas: communication skills and ethics instruction. The Liberal Arts and International Studies Division (LAIS) – now called the Division of Humanities, Arts, and Social Sciences – proposed two 3-credit courses for the general engineering curriculum to address these gaps: communication / technical writing and ethics. However, the university was unwilling to relinquish valuable credit hours outside of the technical curriculum, one of the perennial problems of engineering education Grose (2013) articulates. In response, LAIS developed a 4-credit course meant to achieve the outcomes of both first-year writing and ethics courses in one semester. This challenge forced instructors to develop a unique, highly integrated course with a combined lecture / seminar format: students spent 1–2 hours per week in large group lecture of 200–320 students, where lectures on case studies, ethical codes, and moral theories were delivered by rotating subject-area experts, and then spent 2–3 hours per week in small classes of 18–22 students where they engaged in a Socratic seminar focused on discussion, peer review of writing, and critical reading and research designed to reinforce the lessons learned in lecture.

Alongside the success of NHV, such as its recognition as an Exemplar in Engineering Ethics Education by the National Academy of Engineering in December 2015, an interdisciplinary team of faculty developed a new first-year honors course called "Innovation and Discovery in Engineering, Arts, and Sciences" (IDEAS) to combine the ethics and communication learning outcomes of NHV with the learning outcomes from the Introduction to Engineering Design core course over two semesters. The IDEAS course aimed to add yet another facet of disciplinary integration: introduction to design thinking and problem-based learning. Our goal in IDEAS has been to build upon the success of NHV to design a curriculum that encourages knowledge transfer of ethical awareness between technical and non-technical courses. This integration helps inform the values inherent in decision making, emphasizes global and cultural perspectives and broader awareness of the environmental and societal contexts of engineering, while simultaneously challenging the social and psychological barriers of disciplinary silos that predetermined the placement of where ethics "belonged" in engineering education. In both courses, the curriculum focuses on three key pedagogical tools to achieve these outcomes: multidisciplinary synthesis, collaboration, and reflective portfolios.

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CURRICULAR DEVELOPMENT AND IMPLEMENTATION

Since its earliest iterations, NHV faculty have responded to contemporary theories about approaches to integrating ethics in engineering education. These include teaching philosophy texts and ethical frameworks (Unger 1994; Herkert 2000), to examining case studies (Lynch & Kline 2000; Herkert 2005), to expanding socio-technical understanding (Kline 2002) and balancing micro- and macro-ethics (Herkert 2005). Faculty in IDEAS and NHV currently employ practical and experiential pedagogy to build on students' lived experiences (Voss 2013) and seek to guide them through an exploration of the world with a structured, but open curriculum that Pfatteicher (2015) describes as "sifting, winnowing, and scaffolding" to prepare them for an evolving, globalized workplace. Overall, we continue to develop active pedagogy that engages students in open-ended questions to foster ethical awareness and behavior (Bairaktarova & Woodcock 2017). As our courses continue to evolve, we are moving more towards a pragmatic approach to ethics instruction and away from the dominant approaches of codes, cases studies, and ethical theories (Zhu & Jesiek 2017). Zhu and Jesiek note that these dominant approaches decontextualize ethics and presuppose that there are clear, universal solutions to ethical problems. By acknowledging how context matters, "ethical decision-making in engineering becomes a communicative and relational practice, with engineers acting as decision-makers who are connected with humans and non-humans who may be directly and/or indirectly impacted by their decisions" (p. 670).

Additionally, in NHV we have striven to move beyond the abstract presentation of professional codes to discussing concrete stories and current events in order to increase ethical sensitivity (Jagger 2011; Lind & Swenson-Lepper 2013) and cultivate moral imagination and moral judgement (Pardales 2002). Holsapple, et al. (2012) show that students perceive codes as merely rules and laws that lack complexity and real-world application. Instead, as Wang, et al. (2015) suggest, engineering ethics must be interpreted and operationalized, and must include dialogue with varied stakeholders and perspectives. Through these activities, we hope to address the issue that "Since the Professional Engineer's Code of Ethics was written by engineers, for engineers, it . . . does nothing to help engineers see ethical dilemmas through the eyes of non-engineers . . . [and] contributes nothing to our students' understanding of either ethical systems, or the shared language in which ethical problems and solutions are couched" (Haws 2001, p. 224). Through the seminar format, students engage in discussions, rhetorical activities, and writing assignments that increase awareness about ethical implications for citizens, society, policy, and culture, as a method to analyze and apply ethical decision-making to real-world engineering contexts.

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MULTIDISCIPLINARY SYNTHESIS

In both NHV and IDEAS, our objectives are to meaningfully synthesize personal and professional ethics within a curriculum integrating engineering with humanities and social sciences. Thus, the foundational content of the syllabus already ties together elements of multiple disciplines: for instance, including writing and argumentation alongside moral reasoning and ethical analysis. In the process, we emphasize professional ethics and varied perspectives on values via literary readings and case studies that have a strong central narrative of engineering and/or environmental impacts (Berne & Schummer, 2005; Adams 2008; Hersh & Stapleton 2005; Hersh 2016). Students practice close reading and analysis, communication in many rhetorical modes, and evaluation of and reflection about the wider context of engineering practice. Over the years, faculty developed standardized writing assignments emphasizing argumentation, analysis, synthesis, and research based on issues in personal, professional, and environmental ethics. The final research paper was designed to evaluate how students could apply ethical decision-making for a current engineering ethics dilemma. Students are assessed on their ability to understand the dilemma from multiple perspectives, consider various stakeholders, form and support ethical arguments, as well as illustrate effective, professional communication skills. The final research paper therefore is itself a synthesis of learning throughout the semester.

Using NHV as a foundation, the new first-year honors course IDEAS attempts to integrate ethical sensitivity at every step of the engineering design process through lessons and activities that deliberately highlight the ethical dimensions of user empathy, problem definition, stakeholder engagement, communication of outcomes, and analysis of contexts and impacts. Our overall theory of change is to simultaneously infuse engineering problem solving with values-sensitive analysis and design (Sandler 2012). With the inclusion of real-world design problems that students identified and solved, there is a basis for learning about and engaging with ethical issues. For instance, in the first semester, students analyze places and spaces through writing and hand graphics and identify personal and community values; in the second semester, students define, propose, and solve the local design problem while practicing stakeholder engagement, oral presentation, and computer graphics skills.

Throughout both semesters, ethical awareness, sensitivity, and judgment are assessed in assignments and projects requiring stakeholder engagement, teamwork, research, design, and communication. For instance, an ethical decision matrix is included in the problem identification process; sensory observations, aesthetic analyses, and ethnographies are required for a spatial investigation; mapping, listening exercises, and community interaction are steps in design development; and an ethics charrette takes place alongside the final design solution (Kirkman 2004). As the IDEAS course

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has developed out of the lessons of NHV, instructor teams continue working together to merge and create content, all while paying attention to what practices and assignments are most effective for student learning.

COLLABORATION AS A TOOL FOR ETHICS INTEGRATION

We have found that both faculty and student collaboration across backgrounds and disciplines is crucial for success in integrating ethics in engineering curriculum. Professors teaching NHV specialize in history, literature, rhetoric, environmental studies, philosophy, economics, and religion. Each instructor brings perspectives from their area of expertise to the challenges of engineering ethics and communication, which increases faculty professional development as well as brings added value to student learning. Similarly, during the initial two-year pilot of IDEAS, each section was team-taught by one Humanities faculty member and one Engineering faculty member, and a six-person team of instructors from both Divisions worked to co-develop all curriculum. This method allows students to see in real time how different disciplinary lenses inform analysis of engineering issues when instructors from varying backgrounds commented on the same design or ethics problem. Students have reported that this is one of the most impactful aspects of the course in terms of improving their learning.

Student collaboration in both courses takes the form of team presentations and projects; indeed, much of the IDEAS curriculum over the entire year involves students working in teams of various sizes, from pairs to groups of five. We also employ group collaboration for some of the assignments that are focused on writing and ethics because one of the learning outcomes for engineering design courses is to learn and practice effective strategies for working in teams. For instance, when students are midway through their final engineering project, their teams engage in an ethics charrette (Kirkman 2004). Here they approach ethical decision-making about and analysis of their solution through group discussion, dialogue, and teamwork in a similar way to how they apply design and risk analysis tools to their solution. Ethics therefore does not take place in a vacuum of individual moral reasoning but is applied directly to an engineering solution.

ASSESSMENT AND IMPACT

Emphasis on collaboration and on multidisciplinary learning invigorates the way we conceive the learning objectives, and consequently, the assessment of the course. Assessing writing is challenging and somewhat subjective but assessing ethics knowledge and its application is even more

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fraught with pitfalls (Keefer, et al 2014). Instructors can say "I know it when I see it" for both of these areas, but that does not translate into measurable outcomes and comparative data. As part of a departmental ABET assessment plan for all required courses and to emphasize the multidisciplinary integration of the course, instructors filled out a spreadsheet rubric with 6 course objectives for each student. These objectives included both communication and ethics outcomes: 1) application of ethical concepts, 2) critical thinking and reading, 3) constructing an argument, 4) conducting research, 5) writing and mechanics, and 6) engineering in context. Students were ranked as lacking (1), emerging or developing (2), proficient (3), or advanced (4). In the first couple years of assessment data, we noticed that students were averaging between 3 and 4, which is what we would hope, but that those scores were falling over a series of semesters. Institutionally, we were exceeding the expectations for assessment, but internally, the data were not that useful for improving instruction and understanding what students "knew or could do" by the end of the course. We continued to use these assessment rubrics through 2017, but there is a new assessment leader and committee at the university level, and we are in the stages of developing what systems and inputs will be most important for developing our course instruction. The drive to develop clearer learning objectives for all our curricula will certainly shift the focus of instructors as we create new assessment methods.

REFLECTIVE PORTFOLIOS

After years of iteration with these courses, the teaching team sought ways to better measure ethical reasoning and synthesize engineering concerns with ethical decision-making. In NHV we eliminated the final exam on lecture and reading content in Fall 2018 and replaced it with a final portfolio assignment where students can showcase their growth in writing and critical thinking while simultaneously contextualizing the ethics course content.

In IDEAS, we have also incorporated reflective portfolios alongside other assessment strategies, including student surveys on ethical awareness, faculty self-evaluation on achieving learning objectives, and formative grading of formal reports and presentations on design solutions—both of which included analysis of ethical implications. We have found that the portfolio best showcases student learning, understanding, and application of ethics in the context of engineering, especially when there is an explicit requirement for student reflection on this topic. The portfolio serves as the ultimate model for synthesis by prompting students to explore, interrogate, and make sense of their learning journey scaffolded by ethical considerations, as well as bring to light an aspect of engineering design education that is often simply implicit or embedded in other outcomes (McDonald 2012).

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All of these strategies have led us away from instruction on ethical theories and moral philosophy, and toward an emphasis on ethical underpinnings of positions and decisions in formative assessments (Keefer et al., 2014). Rather than deductive reasoning, we privilege inductive reasoning. This year, we are implementing a pre-assessment to investigate the ethical assumptions of a proposed design solution for the city before students have had any explicit ethics instruction, and then we will compare results with a post-assessment of the ethical implications of their final design project. This, we hope, will illuminate both what is effective and what is missing in ethics instruction within the course.

The success and value of reflective portfolios has helped us make the case in both NHV and IDEAS to involve students more in self-assessment, synthesis of their own learning outcomes, and analysis of the materials they choose to highlight in a portfolio. It continues to confirm students' appreciation for common elements such as paper expectations, common readings, lecture content and the holistic thread of ethical reflection to tie it all together.

LIMITATIONS AND CONSIDERATIONS

While we have overcome some challenges to integrating ethics into the first-year engineering curriculum, there are more issues to address. These tend to fall into the larger structural and organizational context of the university, many of which are out of our control. For instance, NHV, like many first-year Composition courses in other universities, is taught by a significant number of adjuncts. Because of its interdisciplinary nature and highly specific content, it is a course that almost no one comes out of graduate school prepared to teach. Another challenge is that in order to achieve its outcomes, assessment has shown that small class sizes are required to facilitate a Socratic discussion as a means to develop ethical awareness and sensitivity, and intensive feedback is required for improving writing skills. Administratively, all this translates into using more resources of people and spaces. And even while our Honors Programs have the financial resources to support small class sizes and co-teaching in IDEAS, there are a limited number of faculty able and willing to teach the content: the mindset of integrative pedagogy is not something that is generally emphasized in the graduate programs of professors who end up teaching first year courses.

Additionally, students are not used to learning in an integrative environment. The American educational system has moved towards standardized testing and early disciplinary expertise for highly capable students (AP, for example) so that when confronted with a lesson that melds, for example, science fiction with adaptive design, students are confused at best and resistant at worst. Even in IDEAS, where students have applied to and been accepted into an honors program that

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emphasizes integrating science, engineering, and the humanities and arts, some are stymied by the curricular approach, especially in juxtaposition to their very rigid discipline-centric first year courses. The siloing of disciplines creates artificial barriers for the application of multiple methods and interdisciplinary content, but through the integration of ethics in NHV and IDEAS we have established the important placement of ethical sensitivity and judgment in an interdisciplinary first year core course. With NHV as the guidepost in the first year we need the momentum of ethics in disciplinary context across all four years.

Future Directions

With all this in mind, we plan to implement both large- and small-scale interventions for continued improvement. On the large-scale, we are developing best practices for portfolios with professional ethics as a primary thread. We believe portfolios can help transfer knowledge and experience between technical and non-technical courses, and they can become a holistic collation of a student's education and active learning experience. With an expectation of synthesis and reflection, portfolios could illustrate several aspects of a student's ethical growth (worldview, life experiences, perceptions and bias) and intellectual growth (knowledge, metacognition, technical skill, application of problem solving). We hope to show, after pre- and post-assessment, that portfolios allow students to critically reflect and inter-relate the larger context of whole-curriculum learning and personal learning objectives, and potentially help students make the implicit contexts of ethics, analysis, and reflection explicit and transparent. On the small-scale, we continue to do more ethics micro-insertion across the curriculum with multidisciplinary readings that contextualize case studies and current events, Socratic dialogues and open-ended questions, and synthesis of learning objectives into scaffolded assignments like the research paper. Throughout its iterations, the foundation of the NHV and IDEAS curricula is the understanding that ethics instruction is most effective when it moves beyond a single lecture or module within a course, and when it is linked to real-world, hands-on problems. We want students to understand and reflect upon the ethical underpinnings of their careers, not just as a lens for design heuristics but as an essential tool to navigate any engineering endeavor.

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AUTHORS

Sarah Jayne Hitt has taught courses in communication, literature, history, engineering design, ethics, and cultural studies during her fifteen years in higher education. As a founding faculty member at the New Model Institute for Technology and Engineering in Hereford, United Kingdom, she acts as Liberal Studies Lead for the academic team. She has led teams of engineers and liberal arts faculty to develop interdisciplinary courses such as "Nature and Human Values" at the Colorado School of Mines, which was designated as an Exemplar in Engineering Ethics Education by the National Academy of Engineering, as well as a first-year honors course integrating engineering design, communication, and ethics called "Innovation and Discovery in Engineering, Arts, and Sciences." At Mines she also served as Director of the Writing Center and of the McBride Honors Program in Public Affairs, which prepares engineering students for innovative, service, and leadership roles in their careers. She holds a Ph.D. in Literary Studies with a focus in Literature of the American West and was a Fellow of the Daniels Fund Ethics Initiative.

Cortney E. P. Holles is a Teaching Professor at Colorado School of Mines. She has taught and helped shape Nature and Human Values, the interdisciplinary freshman writing and ethics course, since 2004. She co-created a two-course series in Science Communication in 2009, and these courses integrate communicating with public audiences with analyses of cases involving scientific uncertainty and perceptions of risk. She also teaches Service Learning since 2013, a course combining academic study of individual and systemic poverty and privilege with committed service to a local non-profit benefitting an under-served population. She is working on a doctorate in education, researching faculty-student interaction and its impact on well-being for her dissertation. Outside of school, she is focused on exploring the world and nurturing authentic relationships as a mom to two teens.

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Toni Lefton is the Executive Director of the University Honors and Scholars Programs and the Director of the McBride Honors Program in Public Affairs at the Colorado School of Mines. She teaches interdisciplinary honors courses that underscore the social, cultural, environmental, and ethical contexts in which engineers operate. Toni has also taught creative writing, comparative literature, engineering design, and the core communication and ethics course Nature and Human Values. Since joining the Mines faculty in 1999, she has worked on integrating arts and humanities in the STEM classroom by incorporating multidisciplinary lenses, contextual learning, and creative expression as a modality for problem solving, critical thinking, empathy, and civic engagement. Toni has also been the advisor for *High Grade*, Mines award-winning arts journal since 2000. She has served as a coach for the Mines Ethics Bowl team, faculty friend for the Visual and Performing Arts Themed Learning Community, advised the Creative Arts Club, the Philosophy Club, Creative Writing Club, and Anonymous Right Brains. Toni is an active member of the National Collegiate Honors Council (NCHC) and the NCHC Faculty Institute which develops experiential, place-based programs for students and educators. In addition, she has been involved in national STEM to STEAM initiatives with the National Endowment for the Arts and National Science Foundation, and was a Daniels Fund Ethics Fellow where she partnered with Sarah Hitt to integrate ethics into the first-year honors curriculum. In her other life, Toni is a published poet and writer. Her poetry, fiction, and essays have appeared in *Narrative, The Crab Orchard Review, Kalliope, The Sun Dog, Hayden's Ferry Review, The Kudzu, Thin Air, Ellipses,* on *National Public Radio* and *Ms. Magazine*, among others. Her first book, *Everyday Crimes* won the Anhinga Prize and she has been a finalist for a Pushcart and the Emily Dickinson Prize in Poetry.