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Improving Undergraduate Engineering Ethics Through Application of Engineering Management Theory: An Empirical Study of a New Course's Impact

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Abstract

As a profession, engineers are expected to serve as role models of ethical behavior. Engineering educators should play a key role in molding ethical engineers by ensuring that engineering ethics becomes an increasingly important component of engineering education. This study explores how inductive teaching techniques can be effectively utilized to improve ethical reasoning of engineering students by strengthening undergraduate student's awareness of and ability to apply ethical standards to complex decision making.

The need of providing an ethical foundation for students in engineering programs is well recognized and a clear expectation for programs seeking to gain or maintain ABET accreditation. Despite clear standards that engineering programs should provide an understanding of professional and ethical responsibility, recent literature points to numerous issues regarding the ethics component of engineering education including insufficient or sporadic coverage of the topic and use of ineffective case studies. As part of a larger redesign of the industrial engineering program at Montana State University (MSU), an existing two credit course on Professional Practice and Responsibility was replaced with a three credit course on Engineering Management and Ethics. The redesigned course made extensive use of inductive teaching techniques to promote deeper student engagement with the ethical issues surrounding engineering and managerial decision making. Qualitative and quantitative measures are utilized to understand changes in student behavior between the start and end of the course. Quantitative results and analysis using data collected through the Engineering and Sciences Issues Test (ESIT) found a significant ($p = 0.014$) improvement in student reasoning while supporting data indicated high levels of student engagement and enjoyment. Areas for future study and improvements are discussed.

Introduction

In light of the near constant onslaught of front page news regarding the transgressions of our corporate citizens and leaders, it seems that the ethical norms of organizations are in need of strengthening. As a profession, engineering recognizes the importance of ethical behavior, citing it as the first obligation of a newly graduated engineering student,[1] and as the final canon of the NSPE Code of Ethics.[2] Given this recognition, engineers should take a leading role in serving as a positive role model for the ethical behavior expected within a healthy society. Engineering educators play a key role in developing engineers who see this role as a key aspect of their professional responsibility. By ensuring that engineering ethics becomes an increasingly important component of engineering education, educators can model the way to instill these behaviors in professional practice.

The need to educate engineering students in a way that promotes ethical behavior is widely recognized. In fact, instilling an understanding of the importance of just this type of behavior is a requirement to achieve accreditation for engineering programs in the U.S.[3] Unfortunately, it appears that creating change in the ethics of college students is a difficult task, as a large number of studies that have found little to no discernible change in measured behavior following the occurrence of an intervention.[4,5] Despite this lack of success, most studies note gaps in their approach and point to potential directions for future research, with the hope that the application of new or different techniques can promote the desired outcome. Given the importance of instilling this behavior in society, it is critical that engineering educators and researchers continue to seek out effective approaches. This article reviews the quest to find such an approach in a redesigned industrial engineering course at Montana State University (MSU).

Literature Review

The literature investigating how college students in general and engineering students in particular can learn and apply the concepts of ethics is considerable. While some writing laments the lack of ethics focus in current engineering programs,[6,7] most continue to seek more effective ways to incorporate ethical training into engineering education.[7,8,9] Why are engineering educators so focused on this soft skill? Of course, there are the external forces, such as accreditation standards on ethics[3] and professional standards,[1,2] but are these forces enough to drive this level of research, or is there something deeper? Perhaps the motivation comes from a combination of the altruistic need to make society a more just place and the fear of the damage that could be wielded by unethical engineers? An investigation of the literature on engineering ethics education provides direction on the answer to this question.

The investigation begins with the question of how faculty currently teach students about ethics? In his analysis of a three-year span of papers published through the American Society of Engineering Education (ASEE), Haws summarized the prevalent techniques as follows:[10]

1. Education on the content and application of Codes of Ethics
2. Incorporation of humanist readings
3. Providing a grounding in ethical theories
4. Application of ethical heuristics
5. Utilization of case studies
6. Incorporation of service learning

Given this basic understanding of how ethics instruction is delivered the next question becomes, how do educators understand the ethical behavior of their students? In order to understand this behavior, a variety of different approaches have been utilized. The most basic approach utilizes instructor designed surveys within individual courses.[11] A more innovative recent approach examined the results of the fundamentals of engineering exam (FE) to gage ethical behavior of a large number of recently graduated engineers.[12] Across the literature, the most common approach utilizes the Defining Issues Test (DIT).[5,13,14] The DIT is a widely validated instrument which utilizes scenarios to understand the moral development levels of participants, based on the work of Lawrence Kohlberg.[15,16] Recently, two promising new instruments focused on engineering behavior have appeared in the literature. The first of these, the Student Engineering Ethical Development Survey (SEED), is still under development.[17] The second, the Engineering and Sciences Issues Test (ESIT), is based on the DIT and utilizes scenarios that are more consistent with the types of situations that practicing engineers might encounter.[18]

Armed with an understanding of the available paths to measure student development, educators must look to understand which methods are effective in promoting change within our students. Unfortunately, despite the importance given to ethics in engineering education, and the level of activity around promoting ethics through the engineering curriculum, few studies have found significant difference in student behavior following delivery of ethics materials.[12] Reasons offered for these shortcomings range from differences in curriculum structure,[18, 19] to convergent thinking promoted by codes of conduct,[20,21] to shortcomings in the content of traditional case studies.[11, 22] Despite the relative lack of success in creating a difference in student behaviors or perceptions, most studies appear hopeful that more effective methods can be discovered and deployed.

This hope seems to manifest for two primary reasons. The first is the belief, supported by a variety of evidence, that active learning techniques and the ill-structured exercises of problem based learning (PBL) are highly effective in helping students do the types of deep thinking required to evolve the ethical basis of their reasoning and decision making.[21,23] The second is the recognition that the current generation of students is highly interested in sustainability and issues of social responsibility and the belief that by harnessing interest in this area, faculty can engage students in ethical issues that truly interest them.[24]

Using this understanding of the prevalent issues that appear to hinder the effectiveness of engineering ethics instruction, and potential paths to improve effectiveness, a new course was designed to support the ethical decision making of industrial engineering students at MSU, a Carnegie I Research University.

Course Design

As part of the assessment and subsequent major redesign of the industrial engineering curriculum at MSU, the need for additional student exposure to management materials was identified. In order to substantially close this gap, an existing two credit junior level course on professional practice and ethics was redesigned to a three-credit course focused on engineering management and organizational theory with applications in ethics. Figure 1 contains an overview of the course composition. As illustrated in Figure 1, the course is built on a foundation of management theory which supports a more complete investigation of the work of managers and theories of motivation and leadership. The topic of ethics is woven throughout these materials and provides the capstone topic for the course.

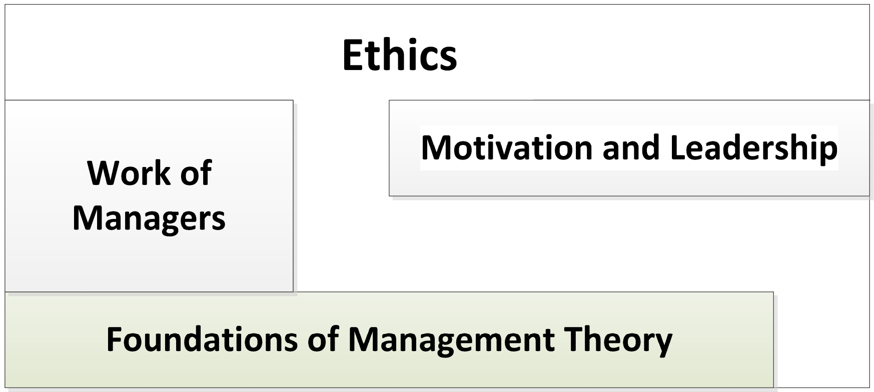

Figure 1 - Relationship Between Core Course Topics

The core motivation for the redesign of the course was an identified need to include greater coverage of management materials for the program's graduates. The added benefit of moving the focus of the course from professional practice to specific applications associated with management and organizational theory, was the ability to utilize the ill-structured problems common in this domain for analysis and discussion of ethical issues. Previous work into the effectiveness of case study applications for teaching engineering ethics have shown that standard cases (e.g. the Challenger disaster) are ineffective at promoting changes in student behaviors and that ill-structured problems might present an improved path to achieving educational objectives.[20, 21]

In order to provide students with a foundation from which to build their ethical reasoning, the core *Exploring Management*[26] text used in the course was supplemented with a customized text that included not only additional materials on management and organizational theory, but adopted key sections of the text *Ethics, Technology, and Engineering: An Introduction.*[25] Included in this material were readings on the responsibilities of engineers, engineering codes of conduct, normative ethics, designing for morality and the ethics of sustainability and technology. This material provided the core of three of the delivery techniques outlined by Haws by covering professional codes, ethical theories and heuristics.[10] As illustrated in Figure 1, these ethics materials were introduced early in the course and regularly revisited and expanded upon throughout the semester. Additional materials on ethics were provided through periodic supplemental readings from a variety of sources. These materials provided a foundation to build additional understanding of ethical reasoning using a variety of both inductive and traditional teaching methods including small and large group discussions (both face-to-face and online), classroom debates, formal written papers and examination questions requiring students to build an argument based on a prescribed ethical framework.

Three separate traditional teaching techniques were utilized to promote students' ability to apply ethical frameworks and considerations to the decision making process. The first was assignment of a substantial paper examining an ethical dilemma regarding a post-graduation employment opportunity.[27] The dilemma involved a soon to graduate engineering student whose immediate career plans are changed due to a family emergency and the subsequent potential for employment in an industry whose work runs counter to the student's personal and family beliefs. The second teaching technique employed was the utilization of ethics related application questions on each of the two course exams. In both exams, these questions represented approximately 20% of the available points and asked students to synthesize how a given ethical framework applied to a management system they designed. The final traditional approach was that of short opinion pieces written within the online class discussion boards regarding brief case elements from the assigned text.[26]

Since the literature points to a greater probability of influencing student thinking with inductive techniques, the course focused on these applications. These elements were frequently deployed and enabled not only greater student involvement, but provided the opportunity for more real-time feedback from both the instructor and other members of the course. The first of these elements involved small group discussions. In these discussions, an ethical dilemma was provided for students to work through in their teams. Teams were assigned randomly by the instructor at the beginning of the semester and remained consistent throughout the course. For small group exercises, the team was allowed a brief time to discuss elements of the dilemma, such as what the key decision criteria should be, the recommended path forward, etc. One example of such a discussion was the comparison between the tenets of Taylorism and those presented by Crawford in *Shop Class as Soul Craft.*[28] Following the small group discussions, the entire class would come together to discuss these elements. Using this format, the course allowed all members to express their opinions in the relative safety of a small group with whom they were familiar, while using the larger group to promote the type of rigorous discussion and debate that Dryud has argued is essential for students to engage in truly appreciating ethical issues[29] and as an avenue for the instructor to prompt students to consider key issues and vantage points.

The second major inductive element deployed in the course was the utilization of online debates and critiques. This element utilized the opinion pieces created by students on the course's online discussion system described previously. These debates focused on contemporary issues ranging from sustainability to the idea that corporations are people. Students were then given assignments to debate these pieces with other members of the class using the course materials as a foundation for their argument.

The third major inductive element in the course was the use of large group discussions. While these discussions often were follow-on items from the small group discussions described above, they were also stand-alone elements based on course readings or other assignments. The most fruitful of these occurrences, in terms of the depth of student engagement perceived by the instructor and student reported enjoyment, utilized the assigned paper described above as its foundation. In this lengthy and far-reaching discussion, each of the questions assigned in the paper were raised and the students were encouraged to discuss how they approached the answer in their paper. This led not only to members of the class sharing insights they had gained from sources outside the assigned course materials, but also to vigorous debates regarding the various recommended paths and the reasoning supporting those recommendations.

The final inductive element incorporated into the course was that of live debates between teams. These debates combined the strengths of the small group discussions (e.g. safe environments, more time for individual voices, etc.) with the depth of understanding displayed in the large group discussions. Teams were given a finite amount of in class time to prepare a topic, based on recent course readings, then debating that topic with another team in the class. Generally, large group discussions followed each of these debate topics, allowing all members of the class a voice on each topic, even if it was not one assigned to their team. Debate topics ranged from aspects of managerial decision making, to conflicting management theories, to the ethical components of decision making in a globalized world.

The course introduced basic concepts of engineering ethics early in the semester and used this framework to support the discussions outlined above as new materials related to management and organizational theory were introduced. As the semester progressed, more advanced ethical topics were periodically incorporated to further support the new management or organizational theories being discussed. The course's final module returned to ethics, focusing on higher levels of moral development as defined by Kohlberg.[30] Figure 2 displays the interaction between the techniques utilized to cover ethics related topics in the course.

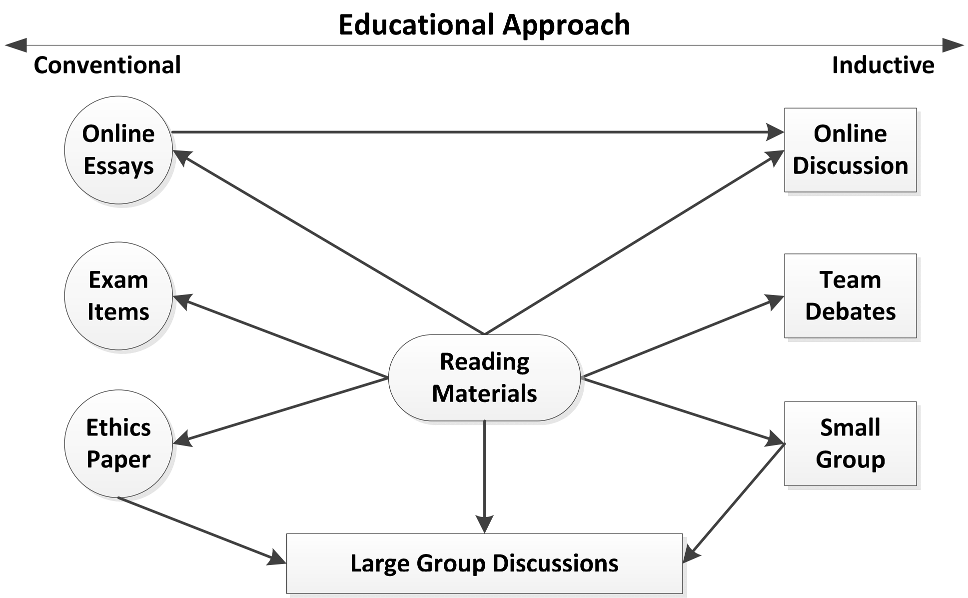

Figure 2 - Relationship Between Teaching Approaches Used in the Course

Results

The effectiveness of the course in changing student behavior in terms of ethical decision making and moral development was measured in a multi-modal way. Qualitative data was gathered from student feedback regarding their course experience and instructor observations of the group activities previously described. Quantitative data was collected using the ESIT. As mentioned previously, the ESIT builds off the DIT using the Kohlberg development model. The instrument sought the students' understanding of issues regarding a number of engineering situations. An example of ESIT content is a scenario explaining a financial conflict of interest and then asking students to rank the importance of issues in the case ranging from potential impacts on career path to popularity with coworkers. The ESIT was first deployed near the beginning of the semester, prior to beginning any instruction on ethical issues, and again at the conclusion of the course. Additional ESIT data was collected from a group of IE freshman and seniors at the university to understand any potential differences in these populations compared to the study group.

Qualitative data was collected primarily through instructor reflection on the quality of the student discussion regarding ethical issues. The most striking example of this data involves the use of a simple case study introduced early in the course. This case was introduced during coverage of the initial round of ethical materials in the course texts. The case involves an engineering manager in the midst of building a competitive bid when one of his employees brings him an envelope that is said to contain all of the cost data from a leading competitor. The students were asked what action they recommend the manager take. In the first use of the case, nearly 90% of the class recommended not only opening the envelope, but also utilizing the data to prepare their own proposal. There was almost no concern regarding the actions of the employee or consideration of any ramifications for those actions. In fact, the largest concern voiced by students was that the data contained in the envelope might be misleading as part of an industrial sabotage attempt. These viewpoints illustrate individuals who are within the pre-conventional levels of Kohlberg's moral development scale.[30] At this stage, individuals are concerned with obedience primarily to avoid punishment, which closely matched a phrase frequently uttered in the discussion that 'nothing illegal' was done. When the case was revisited at the end of the course, the majority of students were not interested in opening the envelope and instead focused most of their discussions on conventional and post-conventional issues around social norms and social contracts. Subsequent large group discussion recognized the transition from one level to the next and gathered student input regarding which aspects of the course may have contributed to this change. Many of the techniques depicted in Figure 2 were mentioned, with most students citing the large group discussions and debates as the most impactful.

The quantitative data collected using the ESIT is contained in Table 1. As shown in the table, the initial data set contained 23 completed surveys from both the pre and post course rounds of data collection. After applying the ESIT authors criteria for eliminating student responses[31] and removing responses where the student did not participate in both rounds of data collection, seventeen matched pairs remained for analysis (n = 17).

The PSCORE and N2 Scores calculated from the survey responses were compared using a paired-t test in Minitab.[18] The results of the tests found no significant difference in the pre and post tests using the PSCORE measure (p = 0.138), but did find a significant difference in the N2Score measure (p = 0.014). These split results necessitate a better understanding of what exactly these calculations are intended to measure. In short, "the PSCORE is interpreted as the relative importance participants five to principles moral considerations (Stages 5 and 6) in making a moral decision," while the N2Score accounts not only for the effect associated with acquisition of new thinking, but also "systematic rejection of simplistic thinking." [32] Rest, et al. further argue that both types of progress are desirable educational outcomes and show that the N2Score provides a more reliable measure across multiple large data sets.[32]

While the lack of significant movement in the students' PSCORES might be disappointing, the significant movement in the N2Score is quite encouraging. If students can be drawn away from simplistic thinking through course intervention, multiple rounds of intervention may be able to make further progress on the acquisition of new thinking illustrated by the PSCORE.

Table 1 - Results of Pre and Post ESIT Surveys

	Pre Course			Post Course		
Student	Exclude	PSCORE	N2Score	Exclude	PSCORE	N2Score
1		41.67	4.541		48.33	4.585
2					28.33	-0.054
3		43.33	3.307		35.00	2.738
4					40.00	3.616
5		46.67	3.408			
6		70.00	2.250		68.33	4.023
7	Yes	23.33	0.487	Yes	58.33	3.169
8		33.33	2.915		46.67	3.493
9		46.67	4.059		58.33	4.466
10		36.67	2.920		42.37	3.772
11		50.00	2.259		63.33	4.449
12		36.67	2.767		38.33	2.216
13		18.33	0.305		26.67	2.272
14		38.33	2.502		38.33	2.713
15		51.67	3.529		58.33	3.702
16		63.33	3.990		62.96	5.409
17					35.00	2.623
18	Yes	55.00	2.709			
19		56.67	4.285		61.67	4.909
20	Yes	55.17	1.454	Yes	36.67	1.018
21		63.33	4.844		56.67	5.571
22		26.67	2.954		41.67	3.031
23		36.67	3.625		35.00	3.737
24		53.33	2.344		38.33	1.893
25		56.67	1.752			
26		46.67	1.464	Yes	30.00	-0.470

Conclusion, Limitations and Areas for Future Study

As part of the redesign of an industrial engineering curriculum at Montana State University a new course was developed and deployed focused on management and organizational theory. Due to the divergent nature inherent in many managerial challenges, the course presented an excellent opportunity to implement many of the curricular changes recommended in the literature to improve educational outcomes with regard to engineering ethics. Through implementation of a variety of inductive teaching strategies, students were provided the opportunity to think deeply on a number of ethical issues, while gaining new knowledge on ethical theories. Empirical evidence indicates a significant improvement in student ability to reject the simplistic thinking associated with lower levels of Kohlberg's development model.[30] The same thinking that was evident during discussions early in the course.

While the study found a significant improvement in measureable areas, there are a number of limitations. The primary concern is the small data set (n = 17). Due to this small sample, it is ill advised to draw wide-ranging conclusions about the efficacy of the techniques utilized without further confirmatory studies. The second concern is the lack of ability to tie the results to specific actions within the course. Due to the course being a complete redesign, a number of new techniques were implemented in an environment that could not be utilized for a truly controlled experiment. While this broad based approach is consistent with recommendations from the literature, it lacks the satisfaction of being able to pinpoint which techniques were more effective than others.

The significant change measured in one dimension of student behavior is encouraging and points to the need for further work in this area. By designing future studies to include larger numbers of students and more specific control groups, the potential for more far reaching conclusions on the efficacy of the tested techniques can be understood. This will address core limitations of the current study and enable understanding the potential broader impacts of this work.

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