Impact of critical narrative on students' abilities to recognize ethical dilemmas in engineering work

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Introduction

This paper contains preliminary results from a quasi-experimental study that seeks to evaluate the efficacy of "critical narrative" as a pedagogical tool to help engineering students think critically about the broader impacts of their profession. Consistent with ABET Student Outcome (SO) 2 and SO4 [1], we assume broader impacts to include the economic, social, and environmental implications of engineering. Our study also attempts to address issues related to ethics, professional responsibility, and students' perceptions on how these concepts apply to the work they are doing as part of their senior/capstone design projects.

Ethics interventions are notoriously difficult to characterize and assess [2]. Traditional approaches that include engineering-related case studies or exposure to professional codes of ethics are well documented in the engineering education literature [3]. Our own experience with these methods in the classroom have been mixed, and these previous efforts have led to some concern that the overall depth of thought and engagement with the complexities involved in making moral judgements in engineering contexts is limited. Our goal with this research is to extend ethics education in engineering towards something beyond a purely cognitive exercise by engaging students in conversations around morally complex narratives where questions of fairness and justice – moral judgements [4, 5] – are a central focus. This focus leads to enhanced critical thinking.

Background Literature and Previous Research

In the early 20th century, John Dewey defined and promoted critical thinking. Since then, scholars and professors have been trying to fulfill his goal to engage students in "reflective thinking," which is an "active, persistent, and careful consideration of a belief or supposed form of knowledge in the light of grounds which support it" [6]. Scholarship on how to define and measure critical thinking abounds; however, there are still calls [7] for scholarship on how critical thinking is being taught. Our study responds to that call specifically in the field of engineering education. Guided by ABET's SO2 and SO4 urge to get students to consider the impact of engineering solutions in a variety of contexts, we developed an intervention to enhance engineering undergraduates' critical thinking in relation to ethics and professional responsibility.

Using narratives to teach ethics in engineering is not new. Some initiatives have used science fiction, film, or theater to explore ethical considerations in engineering practices and processes [8,9]. Recent work by Bielefeldt [10] explores the difference between traditional engineering case studies, which tend to be generalized and focused on community impacts, and personal narratives as told by both the engineers and individuals impacted by the scenario. Others have used documentaries or reports to help students contextualize real events or challenges or to give background to case studies. More recently some faculty have created narrative based games that explore ethical considerations inside a professor-generated story based on the science of space exploration and colonization [11]. When considering narrative pedagogy, students and professors may share their personal experiences through essays concerning particular engineering problems

[12]. Narrative ethics uses stories to explore ethical issues and possibly "give a voice to individuals whose experiences might otherwise be marginalized or ignored"[13]. The authors could find very little research on the efficacy of narrative ethics within engineering.

Based on the pedagogical scholarship of Goodson and Gill [14], our intervention–the critical narrative–is a purposefully different pedagogical tool, one an engineering student population might not be accustomed to. We define the critical narrative as a "structured, place-based narrative about complex engineering and ethical dilemmas that do not have singular solutions" [15]. Place-based because of the importance of the physical environment, "where the experiences are unfolding over time" [16]. According to Clandinin et al. [17], "The specificity of place represents an essential role in narrative inquiry with the reflection that events impact in each place." Critical because the narratives confront social realities. Akin to critical pedagogy dating back to Dewey and Paulo Freire or critical theory associated with the Frankfurt school, critical narratives encourage students to think of power dynamics. Critical also relates to thinking about moral judgment, when moral judgment is defined as issues related to fairness and justice [4]. Narrative because if students are going to transfer the problem-solving skills they gained in the classroom to considering their impact on a variety of stakeholders, they need an intervention that goes beyond the traditional case study or a module built around memorizing professional codes of ethics.

There are many distinctions between the often effective case study and the critical narrative, though only two will be discussed here because they are most relevant to our study's goals: ways students approach critical narratives and the humanizing effect they can have on students. First, as Pattison et al. [18] highlight, case studies are often presented as reality and drawn from real-life situations; however, this reality is ultimately constructed by someone. Someone chooses what is shared, how it is shared, and what context is provided to the students. What is potentially problematic about case studies is that students may not approach the interpretation of that case study in a critical way because they are aware that the creator of this case study has a specific "answer" to the problem in mind. Burns et al. [19] agree saying "If a case is constructed by 'hinting' at how to examine a set of predetermined principles, the student is being handed a context that is built to reduce the disagreement to such a fundamental level that no actual situation could ever resemble it. Most of the serious moral work is already done". Conversely, when approaching narratives–whether on the page or a podcast – students share an implicit acknowledgement that bias, interpretation, and analysis are an integral part of the genre and, thus, look at the characters and their actions rather than searching for a specific answer to a problem.

The critical narratives we used for this particular study are independently produced podcasts that attempt to objectively present multiple perspectives on economic, social, and environmental issues. One advantage of using the podcast format for educational purposes is that students can listen to them anywhere – creating a relatively low barrier to entry for those students who are

intimidated by reading. Importantly, the critical narratives we selected don't present the issues being explored as having one right answer. Rather, the narrators offer multiple perspectives, along with a variety of details, research, and the hallmarks of a podcast: authenticity, fast pace, sound bites, etc. [20]. Thus, listeners of these critical narratives approach them with different expectations (entertainment versus lesson, for example) than traditional case studies or textbook problems. The other main distinction between case studies and the critical narratives is an ability for students to relate to the material being shared. Traditional case studies, even immersive ones that center around extremely challenging problems, may lack the humanizing element that encourages students to engage with them beyond a purely analytical standpoint. On the other hand, the critical narratives we selected for our study are popular because of their storytelling ability. Storytelling has been documented as a way to build connections, elicit empathy, and teach new concepts [21, 22, 23], particularly because "storytelling is socially constructed and inscribed" [24]. Thus, we used critical narratives, rather than case studies, because the "humanizing effect of narrative...can lead to transformation and reconciliation" [14].

Several previous studies have attempted to evaluate the impact of ethics interventions using a quasi-experimental methodology. May and Luth [25] evaluated comparison- and study- groups for changes in several indicators related to moral reasoning after exposure to ethics education. The intervention was broadly defined and included both standalone courses as well as embedded modules. While some (not all) indicators related to moral reasoning were shown to improve following the intervention, these researchers did not identify a significant difference between standalone course vs. embedded ethics modules. Horton et al. [26] reported results from a quasi-experimental study that evaluated embedded ethics modules in a computer science course. This intervention included discussion, perspective-taking activities and stakeholder analysis around the ethics of contact tracing in a public health context. These researchers reported an increase in students' level of interest and perceived self-efficacy in addressing ethical issues. Our invention also seeks to increase interest and perception regarding ethical issues, and using a similar quasi-experimental methodology, we can review the implications of our intervention on students' perceptions of ethical and professional responsibility. Furthermore, Hess et al. [27] used qualitative methods to investigate empathetic perspective-taking development among graduate engineering students who took an engineering ethics course. The researchers did not explore ethical development in a more traditional sense nor did they include a comparison and study group. Through the use of four case studies, the researchers found changes in the student's perspective-taking.

This research seeks to fill several significant gaps in the engineering ethics education research. First, we built the intervention around critical narrative with the goal of enhancing critical thinking around moral judgment, ethics, and professional responsibility. Second, we are seeking to evaluate the transference capabilities of the intervention to determine if it helps students identify the broader impacts of engineering work. Finally, we hope to evaluate the impact of the intervention on students' perceptions of their responsibility to address these issues as engineers.

Site & Participation

Embry-Riddle Aeronautical University is a private, not-for-profit, PhD-granting university with an emphasis on higher education for the aviation and aerospace industries. Research for this study was completed at the XXXX, residential campus, which is a mid-sized, historically White campus, with a predominantly male student body and an annual tuition costs of over $42,000. Our current study includes a total of eight sections of senior capstone design courses from different degree programs in the College of Engineering. Four sections were identified as the study group (two sections of aerospace engineering - spacecraft design, one section of mechanical engineering - energy systems, and one section of mechanical engineering - robotics), which received the intervention, and four sections were identified as the comparison group (one section of mechanical engineering - biomedical, two sections of aerospace engineering - spacecraft design, and one section of aerospace engineering - aircraft design) that did not receive the intervention. Students completed an informed-consent process. The assignments that were evaluated in this study were required as part of each section's ethics module, but only students who provided informed consent were included in the study. This yielded a total population of N=79 and N=78 for the comparison and study groups, respectively. The current paper evaluates individual qualitative responses to a group discussion assignment that was completed by 60 students in the comparison group and 47 students in the study group.

Intervention

Critical Narrative Assignment

The intervention consisted of discussion-based assignments that were administered in the university's on-line course management system, Canvas. A total of three assignments, each centered around a different critical narrative, formed the basis of the intervention. Because each senior design course had varying learning outcomes, researchers selected three critical narratives that indirectly tied to engineering work and practice, encouraging students to make the connections between engineering work in their chosen discipline and the ethical issues revealed in a given critical narrative. The first narrative, Rhino Hunter [28], discusses current practices that are intended to preserve endangered species by selling permits to hunters to kill them. The second narrative, Hungry, Hungry People [29], describes a plan in the early 20th century to address a food shortage in the US by importing hippopotamuses to the bayous of Louisiana. The final narrative, How do you solve a problem like Fritz Haber? [30], discusses the German, Nobel-Prize-winning chemist and his discovery of a process to convert atmospheric nitrogen into liquid-ammonia fertilizer. Additional details regarding the narratives can be found in Brown et al. [15].

For each of the critical narrative discussions, students were randomly divided into groups of six students. New groups were generated for each assignment. The overall process of the intervention is summarized in Figure 1. Students were assigned the narrative on a Monday and were required to complete the focus questions (see QN 1-5 in Table 1) by Thursday at 11:59pm. Next, students were required to check on the discussion board and read the responses of their peers to the focus questions. Students were asked to respond directly to at least two colleagues

before Saturday at 11:59 pm. Finally, students provided a reflection response (see QN 6 in Table 1) and were asked to identify any changes in their understanding regarding the narrative and the ethical issues that were raised. Participants in the four comparison sections did not complete the intervention.

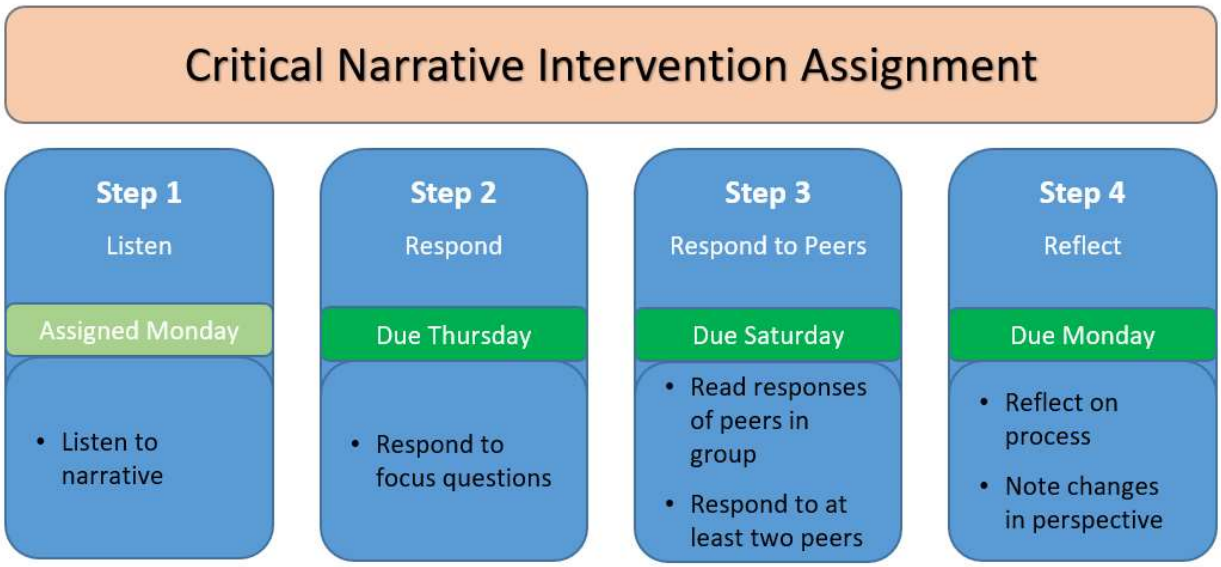

Figure 1. Activities and timeline for critical-narrative intervention

Project-Group Discussion Assignment

Both the study and comparison groups were required to complete the project-group discussion assignment near the end of the semester. Because the primary objective of this research effort is to gain insights on the impact of critical narratives on students' abilities to identify the broader impacts of engineering work and transfer these abilities to their own senior/capstone design projects, researchers designed the group-discussion exercise to be focused on each groups' senior/capstone design project.

The project-group discussion (PGD) was organized in an identical manner to the narrative intervention discussions except the students were assigned to groups based on their project teams and there was no narrative to listen to. Step 1 required each student to respond to the focus questions about their senior design projects (see QPGD 1-4 in Table 1). Step 2 involved reading the responses of group members, and Step 3 asked students to reflect on the process (see QPGD 5 in Table 1). Students were not able to see the responses of their peers until after they had provided their own responses. The focus questions were modified slightly to accommodate the shift in emphasis from the narratives to the student projects. The focus questions for the PGD also did not ask students to identify the connections to engineering since they were already considering their engineering work

Students were only given limited guidance in the assignment prompt regarding the nature of the ethical dilemmas they were required to address:

> *"The goal of this discussion board is to provide your group with the opportunity to discuss and reflect on any ethical issues or dilemmas that you have encountered thus far in your senior design project. Please feel free to emphasize any issues related to economic, social, or environmental concerns. You are also free to address any issues related to professional responsibility or engagement with your colleagues while executing your research and design work."*

Table 1. Focus questions for Critical Narrative and Project-Group Discussion assignments

Assessment criteria	**Narrative assignment questions**	**Project-group discussion questions**
Identify ethical dilemmas/ broader impacts	QN 1: Describe the main ethical dilemmas experienced by the characters in this narrative.	QPGD 1: Describe any ethical dilemmas you identified while working on your senior design project.
Assess/judge characters' responses	QN 2: How would you judge the characters' responses to these ethical dilemmas? Why?	--
Apply ethical reasoning/ moral judgment to engineering work	--	QPGD 2: How did you respond to or address those ethical dilemmas in your project? Why? If you did not respond to or address any identified ethical dilemma in your project, please share your rationale.
Connect ethical dilemmas to engineering	QN 3: How might the ethical dilemmas raised in this critical narrative connect to the field of engineering? Why?	--
Connect ethical dilemmas to society in general	QN 4: How might the ethical dilemmas raised in this critical narrative connect to society in general? Why?	QPGD 3: How did the ethical dilemmas raised in your project connect to society in general?

Table 1(Continued).

Perceived responsibility to address these dilemmas	QN 5: How do you perceive your responsibility to address these types of ethical dilemmas? As an engineer? As a member of society? Why?	QPGD 4: How do you perceive your responsibility to address these types of ethical dilemmas? As an engineer? As a member of society? Why?
Reflection on process	QN 6: Describe how the responses of your colleagues and subsequent dialogue may have changed your perspective on the issues raised by this critical narrative.	QPGD 5: Consider the effectiveness of pausing to consider the ethical dilemmas you may have encountered in your senior design project and the opportunity to discuss them with your peers. Did your perspective on any issues change? Did your peers notice anything you might not have? Was it effective to pause and consider the ethics in and around your design and discuss them as a group online?

Evaluating Student Responses

Researchers developed a rubric in the pilot study to evaluate students' responses to the critical narratives. Researchers modified this rubric for the main study to include criteria to evaluate the project-group discussion responses and reflections. The four key rubric criteria were Identify, Apply, Perceive, and Reflect. The "Identify" criterion evaluated how effectively students identified broader impacts and ethical dilemmas in their senior design projects. The "Apply" criterion evaluated the extent to which students addressed the self-identified broader impacts and dilemmas, and the "Perceive" criterion measured students' perceptions of their responsibility to address these broader impacts and dilemmas as engineers or members of society. The "Reflect" criterion evaluated how students' perceptions of the broader impacts and ethical dilemmas in their senior design projects shifted after engaging in the online group discussion. The rubric included a 5-point Likert scale (see Appendix) to measure ability levels.

Responses to the focus questions for the project-group discussion (PGD) were deidentified and randomized with respect to comparison and study group designations. A qualitative analysis software, Dedoose, was used by the researchers to assign scores for each of the four criteria. Identify scores were based on responses to QPGD1. Apply scores were based on responses to QPGD2. Perceive scores were based on the combined responses of QPGD3 and QPGD 4 since students tended to provide relevant insights regarding their perceived responsibilities in both

questions. Reflect scores were based on responses to QPGD 5. Structural coding was completed by the researchers using the developed rubric criteria as major codes and these codes were weighted on a 5-point scale. Four researchers reviewed the responses of nine students and scored them independently to achieve consistency in scoring. Once rubric calibration was achieved, each artifact was coded by two researchers. If scores were off by two or more points, scores were reconciled via an engaged conversation using scorers' notes. Almost all of the major disagreements in score values were due to data-entry errors. If scores were off by only one point, the two scores were averaged.

A total of 107 students were scored for the Identify, Apply, and Perceive criteria and 60 students received scores for the Reflect criterion. This resulted in a final data set containing 381 scores (107 x 3 + 60). A total of four researchers participated in the scoring. Researchers were divided into teams of two and each team was responsible for half of the students. For the 381 total scores that were assigned, researchers were in agreement on 206 scores (54%) and differed by one point on 175 scores (46%).

Results and Analysis

Basic statistics describing the scores for the study group (SG) and comparison group (CG) are provided in Table 2. The current discussion is limited to group-level effects on the project-group discussion (PGD). Recall that the focus of the PGD assignment was to evaluate students' abilities to identify ethical issues and broader impacts of engineering work, apply moral judgments and ethical reasoning to address these issues, as well as students' perceptions of their responsibilities to address these issues as engineers. Differences between groups were evaluated using an independent sample t-test as well as a non-parametric Mann-Whitney U test.

Table 2. Summary statistics for project-group discussion assignment

	Identify		Apply		Perceive		IAP Average		Reflect	
	CG	SG	CG	SG	CG	SG	CG	SG	CG	SG
N	60	47	60	47	60	47	60	47	32	28
Mean	2.27	2.61	2.53	2.80	2.75	2.81	2.52	2.74	3.39	2.89
Std. Error of Mean	.148	.202	.168	.214	.168	.214	.157	.206	.307	.275
Std. Deviation	.692	.675	.812	.640	.621	.639	.630	.543	.715	.699
Variance	.479	.456	.660	.409	.386	.408	.397	.294	.512	.488
Skewness	.584	.756	.085	-.158	.110	.511	.235	.138	.270	-.115
Std. Error of Skewness	.284	.312	.284	.312	.284	.312	.284	.312	.355	.370
Kurtosis	1.221	.617	-.243	-.026	-.141	.425	-.043	.310	1.109	-.369
Std. Error of Kurtosis	.533	.576	.533	.576	.533	.576	.533	.576	.633	.649

T-Test

When utilizing parametric tests with Likert-scale data it is recommended to test for normality and ensure a sufficiently large sample size [31, 32]. In the current dataset, frequency statistics and a power analysis using *G*Power* [33] were conducted to determine normality and sample size adequacy, respectively. The purpose of this study was to examine project-group discussions among two groups (Comparison Group, CG, and Study Group, SG) using five subscales, Apply, Identify, Perception, Reflect, and as well as the average of Apply, Identify, and Perceive (AIP_Average).

The skewness values were positive for CG across all variables, indicating a slight right skew. The study group (SG) on the other hand, had negative skewness values for Apply and Reflect, indicating a slight left skew. All skewness values were within the range of -1 to +1, suggesting that the data were approximately symmetric. The kurtosis values for Apply were negative for both groups, indicating that the data were platykurtic, or fewer extreme scores than a normal distribution. Further, for CG, values for Identify and Reflect were positive, while Perception and AIP_Avg were negative. For SG, values for Identify, Perception, and AIP Avg were all positive, while values for Reflect were negative. Overall, all kurtosis values were within the appropriate range of -2 to +2, displaying relatively normal distributions, with some slight deviations from normality in the form of slightly skewed or slightly flatter distributions. The power analysis revealed that the sample size was sufficient for conducting the desired analyses.

An independent samples t-test was conducted to compare the means of two groups (CG and SG) on five different variables related to project group discussions (PGD): Apply, Identify, Perception, AIP_Avg, and Reflection. The test revealed that for Apply, the mean for SG (intervention) was higher than CG but not found to be significant, $t(104.994) = 1.884$, $p = .062$, and with a small to medium effect size (Cohen's $d = .265$). For Identify, the mean for SG was significantly higher than CG, $t(100.025) = 2.555$, $p = .012$, with a medium effect size (Cohen's $d = .340$). For Perception, there was no significant difference between the means of the two groups, $t(97.599) = .476$, $p = .635$, with a small effect size (Cohen's $d = .059$). For AIP_Avg, the mean for SG was higher yet not significant compared to CG, $t(104.021) = 1.947$, $p = .054$, with a small to medium effect size (Cohen's $d = .221$). Finally, for Reflection, the mean for CG was significantly higher than SG, $t(57.279) = -2.723$, $p = .009$, with a medium to large effect size (Cohen's $d = -.498$).

Mann-Whitney U Test

An independent samples Mann-Whitney U test was conducted to compare CG and SG groups on the same five variables for the PGD. The Mann-Whitney U test was utilized to compare results with the independent-samples t-test, as a non-parametric test may be more appropriate given the sample size. The results indicate that there was no significant difference in Perception scores between the two groups ($U = 1369.000$, $p = .791$, Cohen's $d = .059$) nor was there a significant

difference in the Apply (U = 1114.500, p = .058, Cohen's d = .265) variable. In contrast, there was a significant difference in Identify (U = 1018.500, p = .011, Cohen's d = .340), AIP_Avg (U = 1097.500, p = .049, Cohen's d = .221), and Reflection (U = 293.000, p = .019, Cohen's d = -.498) scores between the two groups. The comparison group had a mean rank of 49.08 for Apply, 47.48 for Identify, 53.32 for Perception, 48.79 for AIP_Avg, and 35.34 for Reflection, while SG had a mean rank of 60.29 for Apply, 62.33 for Identify, 54.87 for Perception, 60.65 for AIP_Avg, and 24.96 for Reflection.

Discussion

Two variables were identified to have significantly different means using both the t-test and Mann-Whitney U Test: Identify and Reflect. The difference in Identify scores was positive, indicating that the intervention did appear to improve students' abilities to identify broader impacts and ethical dilemmas in engineering work. On the other hand, scores for Reflect decreased for SG compared to CG. This section provides additional discussion and interpretation regarding these findings.

Identify scores for SG and CG were based on student responses to the following focus question:

> *QPGD1: Describe any ethical dilemmas you identified while working on your senior design project.*

Recall that the assignment prompt for the project-group discussion (PGD) did encourage students in both groups to focus on economic, social, or environmental issues as well as any issues related to professional responsibility or working with their colleagues. The most closely-related question that students from the study group responded to about the critical narratives was the following:

> *QN1: Describe the main ethical dilemmas experienced by the characters in this narrative.*

In the critical narrative assignment, students in SG were never told anything specific about which issues (economic, social, or environmental) a narrative addressed or to be on the lookout for anything specific related to broader impacts/professional ethics in engineering. A range of scores was observed for both the study group and the comparison group for this PGD question. For example:

> **Excerpt 1** [Score = 4.5 from Comparison Group]*: One key dilemma that came up as we were designing our aircraft was the amount of fuel and size of our aircraft. Initially, our aircraft required 2 engines and a massive fuel tank in the fuselage. Not only would this increase the cost of the aircraft, but the safety of the pilot would be low especially if he/she would go into combat due to the size of the fuel tank and how easy it may be able to be targeted. Another issue with the necessary fuel is the emissions that would be put into the*

atmosphere. While it is impossible to eliminate them, it would be best if they could be decreased.

Excerpt 2 [Score = 4.0 from Study Group]: *As part of the IGVC team, there are always ethical concerns where autonomous vehicles are involved. What will the developments we make to the autonomous vehicle be used for outside of competition applications? Will the vehicle perform safely in environments that it is unfamiliar with? Will uncertainty in the code cause someone to get injured? How do you program a vehicle to choose how to prioritize human life? Will the vehicle prioritize the passengers within the vehicle or pedestrians around the vehicle? In the event of a railway car situation, will the vehicle prioritize a large quantity of people over that of a few? There are inherent biases that are made when programming the vehicle, but these considerations must be taken into account.*

Excerpt 3 [Score = 2 from Comparison Group]: *The biggest ethical dilemmas encountered included, assuming personal responsibility for the specific work assigned as well as plagiarism of ideas or concepts to make shortcuts in the design process.*

Excerpt 4 [Score = 2 from Study Group]: *The only ethical dilemma that has arisen within the trunk area design group is making sure that the products that we design are safe for the consumer. Since the EcoCar competition has a major focus on the consumer, it is important to make sure that all the rules and regulations set forth by the competition are followed.*

On average, students in SG scored 2.61 on the Identify question. Students in CG scored 2.27, resulting in a difference of means of 0.34 (p=0.012). This suggests that interaction with these specific narratives may enhance students' abilities to identify ethical dilemmas and broader impacts in engineering work. What's missing, of course, is a similar study where students engaged with traditional case studies (and not the narratives) and then completed the same project-group discussion about their work in capstone design. Nonetheless, these narratives, which we have identified as exemplars of critical thinking about moral judgments, do seem to elicit powerful responses from students and enhance their ability to apply these critical thinking skills to their own work as engineers.

Another key observation that appears to be less encouraging is the decrease in Reflection scores for the study group vs. the comparison group. The average Reflection score for the study group was 2.89 vs. 3.39 for the comparison group (p=.009). It seems unlikely that the narratives contributed to a decreased capacity for reflection. One possible explanation is that students in the study group were asked to provide the same reflection for each narrative assignment (total of three) as well as for the project-group discussion. Table 3 provides the reflection score averages for all three narratives and the PGD for the SG. There is a noticeable drop in reflection scores over time as well as a noticeable drop in the number of students in SG even bothering to complete the reflection. It appears that interest and engagement with the same reflection question may wane over time. That doesn't necessarily mean that the reflection component

doesn't add value to the overall experience of the narratives, but results do indicate a potential "fatigue-effect" associated with the reflection scores over multiple assignments.

Table 3. Reflection scores for SG in three narrative assignments and PGD

Rhino Hunter (N=43)	Hungry People (N=40)	Fritz Haber (N=35)	Project-Group Discussion (N=28)
3.12	2.98	2.93	2.89

Limitations and Recommendations

After gathering and reviewing an extensive amount of data, researchers acknowledge the following limitations of the study and provide specific recommendations for educators considering adopting critical narratives into engineering ethics courses.

Limitations

- Don't know lived or professional experience of participants
- Unclear how students' status as seniors may have impacted their participation in the study. Students may
    - not have been exposed to engineering ethics curriculum until their senior design/capstone course
    - be less motivated to participate prior to graduation
    - be more transparent before leaving the institution
    - have internship experience related to engineering ethics
- Classroom experience and how faculty shared study / projected its "importance"
    - Faculty may not have an academic or professional background related to engineering ethics
    - Faculty may not have provided proper incentives for students to participate
    - Faculty may have biased student responses related to ethics with the feedback they provided on each group's senior design/capstone project
- Study design did not directly compare the impact of critical narratives to traditional case studies
- Unclear what comparison groups' ethics modules contained, as engineering departments assign different activities with their respective ethics modules
- Unsure which narrative topic and what number of narratives would be most impactful

Recommendations:

- Ask future participants about their lived and professional experiences
- Conduct another investigation which includes not only senior engineering students but also first-, second-, and third-year engineering students
- Integrate with class more fully, complete direct assessment of final artifact between study and comparison groups
- Compare narratives with traditional case studies to explore critical thinking
- Involve multiple institutions in future work to assess any differences among students
- Provide an opportunity in class for faculty and students to collectively discuss their online project-group discussions
- Include researchers on engineering ethics investigations with diverse lived experiences and varying academic/professional backgrounds inside and outside of engineering

Conclusion

This research project investigates the efficacy of critical narrative as a pedagogical while utilizing a quasi-experimental mixed-methods design. Students in the study group listened to three critical narratives, responded to focus questions about the ethical issues involved in the narratives, responded to peers' responses to the focus questions, and reflected on the process of engaging with the narratives and their peers. After this multiple-step intervention, students completed a project-group discussion assignment where they were asked to identify and discuss any ethical dilemmas or broader impacts that they encountered while working on their capstone design projects. The same project-group discussion assignment was completed by a comparison group that did not experience exposure to the critical narratives.

Study results indicate that interaction with these specific narratives may enhance students' abilities to identify ethical dilemmas and broader impacts in engineering work. These narratives, which we have identified as exemplars of critical thinking about moral judgments, do seem to elicit powerful responses from students and enhance their ability to apply these critical thinking skills to their own work as engineers. Additional research is needed to evaluate the efficacy of critical narratives relative to traditional engineering ethics case studies. One advantage of critical narratives, however, is that students should be able to grasp the moral and ethical complexities of the narratives regardless of their level of understanding or previous exposure to ethical issues that are engineering specific.

Appendix – Rubrics for Scoring Project-Group Discussions

	Description and Scale				
Criteria	**1**	**2**	**3**	**4**	**5**
Identify/ Recognize Broader Impacts (S02/SO4) o Financial impact o Environmental impact o Social Impact o public health o safety o welfare o Global o Cultural o Social environmental o Economic	Does not identify any impacts/ethical dilemmas	Identifies at least one impact with some details or superficially mentions two impacts.	Identifies many details of one impact or identifies two impacts with some details	Identifies more than two impacts with lots of details or identifies three or more details with some details.	Identifies more than three impacts with lots of details
Apply/ Incorporate Ethics and Professional Responsibility (S02) o Moral dilemma/ Ethical awareness o Personal/ Individual Resp. o Tension/ Tradeoffs Risk analysis Made actual changes to address issues Vs. engineers responsible for safety	Does not apply ethics or PR; addresses ethics or PR with little or no coherent effort/strategy; does not offer any consideration of broader impacts	Applies ethics or PR issue by applying only prescriptive code or agency directive to design or ethical dilemma; does not offer an alternative consideration;	Applies ethics or PR by offering alternative considerations for design or superficially mentions how ethical dilemmas might be addressed; Mentions some of the advantages and disadvantages of alternative considerations for ethical dilemmas;	Applies ethics or PR by actually making one change to design or details how ethical dilemmas might be addressed; mentions detailed assessment of alternative considerations for ethical dilemmas;	Applies ethics or PR by making multiple or thorough changes to design or fully considers how ethical dilemma can be addressed; mentions a full assessment of alternative considerations for design or clearly details how more than ethical dilemmas can be addressed

Perception of Ethics and PR (SO4)	Does not perceive ethical or professional responsibility as important; does not situate personal responsibility into societal or professional responsibility	Only perceive codes, agency directives, or generic "safety" (ex. safety) as part of ethical or professional responsibility or somewhat situates personal responsibility into societal or professional responsibility	Somewhat Perceives broader impacts as the ethical and professional responsibility of engineers and/or somewhat connects personal responsibility into societal or professional responsibilities; offers a little detail about responsibilities	Perceives broader impacts to be the ethical and professional responsibility of engineers and/or connects personal responsibility into societal or professional responsibilities; carries some doubt about solutions; offers a lot of detail about responsibilities	Highly perceives broader impacts to be the ethical and professional responsibility of engineers and/or fully connects personal responsibility to societal and professional responsibilities; carries doubt about solutions; offers many and relevant details
Reflect on Process (SO2) ○ Open to change: The student demonstrated a high level of thoughtfulness about the ethical dilemma described in the narrative that suggested a shift or expansion of their understanding of ethics and professional responsibility. ○ Mention Open Mind ○ State Appreciation for critical narrative ○ Reflect on importance story for engineers ○ Perspective change ○ Peer interaction/ Process ○ Score for how impactful was the process	no evidence of an internal dialogue and or questioning concerning the ethical and professional responsibility issues;no awareness of multiple perspectives; NO reflection on process	little evidence of an internal dialogue and or questioning concerning the ethical and professional responsibility issues; little awareness of multiple perspectives; a little reflection on the process	some evidence of an internal dialogue and or questioning concerning the ethical and professional responsibility issues; some awareness of multiple perspectives; situates one's own perspective; includes brief mention of personal responsibility–didn't change/perspective but broadened perspective; some reflection of process	Specific evidence of an internal dialogue and or questioning concerning the ethical and professional responsibility issues; depicts an awareness of multiple perspectives and situates one's own perspective; a lot of reflection on process	A lot and specific evidence of an internal dialogue and or questioning concerning the ethical and professional responsibility issues; aware of multiple perspectives and thoughtfully situates one's own perspective; complete reflection on process

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