



How Engineering Students view Dilemmas of Macroethics: Links between Depth of Knowledge and Ethical Literacy

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Abstract

Global citizenship requires an understanding of global problems including the many ethical dilemmas that muddy the waters in search of solutions to these problems. One way of looking at and assessing a student's ability to consider and evaluate global ethical issues is by examining the student's writing on challenging topics, especially in macroethics where ethical dilemmas tend to be complex, unstructured, and downright knotty. Some challenges students face in analyzing ethical situations may be a result of deficits in underlying skills that prevent the student from comprehensive understanding of the problem at hand. This study explores the possibility that deficits in underlying critical thinking skills are linked to specific challenges students face in their understanding of macroethics dilemmas. Thirty essays written by engineering undergraduate students on the topic of waste electronics are randomly selected from a large sample of more than 250 essays collected from two higher education institutions in the United States. The essays are evaluated qualitatively using two different rubrics, one structured to assess ethical literacy and the other structured to assess critical thinking. Results show a wide range of patterns (nine) in the application of critical thinking to writing about ethical dilemmas and a much smaller number of patterns (four) in ethical literacy expressed in these essays. In evaluating ethical literacy in all samples, we find that students do not consider the codes of conduct of their professional society and give superficial treatment to their professional obligations in the field. Further, most students consider stakeholders in a superficial or limited way. In terms of critical thinking, students struggle most often with creating significance in their writing and in exploring complexities inherent to the macroethical problem provided to them. These results are consistent with other studies and provide support for making ethics instruction a culminating experience for engineering students where multiple skills are applied to analyzing complex ethical dilemmas.

Introduction

As Schattle¹ points out, the concept of global citizenship is not a new one; it can be traced back to ancient Greece. But in contemporary society, the concept and the term seem to have new currency and many higher education institutions continue to renew their efforts toward graduating "global citizens". Despite the interest and motivation in global citizenship, very few higher education units have a uniform strategy in place for how to achieve such citizenship in their graduates. This is especially true for undergraduate science and engineering curricula although some programs have developed international engineering minors outside of the traditional curriculum to encourage and support the development of global citizenship (e.g., the University of Michigan, the University of Illinois at Urbana-Champaign and others).

Higher education institutions arguably have a responsibility to develop curricula that foster "global citizens", either as a consequence of their educational mission, in response to political calls for enhanced national security and global awareness, or in strengthening the employability of their graduates within an ever-globalizing context. Although global citizenship is a highly

contested and multifaceted term, three key dimensions, at least within the study abroad literature, are now commonly accepted:

- Social responsibility (concern for others, for society at large, and for the environment)
- Global competence (understanding and appreciation of one's self in the world and of world issues), and
- Global civic engagement (active engagement with local, regional, national and global community issues).²

Instruction in engineering ethics contains elements of all three dimensions in global citizenship. Ladd³ subdivided engineering ethics into microethics and macroethics. Microethics considers individuals and internal relations of the engineering profession. Macroethics pays more attention to larger societal problems and values the collective social responsibility of the profession in making decisions about technology relevant to the good of society.⁴ Most of the current teaching in engineering ethics has focused on microethics.⁵ As a result, this educational focus may neglect the social nature of engineering practice^{4,6,7} and the global impact that engineers can generate as global citizens.

Addressing the ethical aspects of global citizenship in a crowded, content-heavy engineering curriculum is a challenging task. However, the renewed emphasis on ethics invoked by the ABET Engineering Criteria 2000⁸ points to a broader focus for engineering ethics that goes beyond micro-ethical concerns and provides a near ideal platform for prompting students to think about these global issues. Yet, ethics education has its challenges as many global ethical dilemmas are complex and require well-honed critical thinking skills. Barriers in ethics education in engineering have been explored and a wide variety of ethics curricula developed. This study examines the critical thinking and ethical literacy skills of engineering students in the context of a macroethical problem in order to provide insight into future directions that may increase the effectiveness of engineering ethics education.

Background

Writing is performed for a variety of purposes and for a variety of audiences. It can be taught and assessed in many ways. In the wider literature on undergraduate writing, others have observed^{9,10} that college faculty fail to agree on how to define good writing and thus on how to promote and assess it. Even within engineering education, all faculty do not share the same view of writing literacy.¹¹ However, within engineering education, most can agree on the need for meaningful instruction on ethics in the undergraduate curriculum as mandated by the ABET accreditation criteria.¹² Likewise, critical thinking skills are generally seen to be an essential part of engineering instruction both at undergraduate and graduate levels. In this paper, rather than evaluating writing for writing's sake, we use it as a tool to understand students' critical thinking and ethical literacy with regard to macroethical dilemmas. This perspective is chosen with the practical objective of understanding what kinds of deficits in critical thinking may be impairing ethics instruction and the subsequent development of strong ethical literacy.

Ethical Literacy among Engineering Undergraduates: Ethics issues in engineering have increasingly drawn attention in the past decade and have resulted in a field of research and teaching in what is now called engineering ethics.⁴ ABET's Engineering Criteria 2000 pose substantial challenges for curricular innovation, faculty development, and program assessment,¹³

but engineering ethics has begun to make its mark on engineering curricula. Evidence of this impact includes both required courses and numerous electives in engineering ethics. Lynch¹⁴ reports that nine of the top 10 US engineering schools have some ethics component in their curriculum. However, several researchers^{3,15,16,17,18,19} have criticized the microethics approach that is typical in engineering classrooms. The tendency to focus on an individual agent's possible courses of action (microethics) limits the ability of future engineers to face and respond to the societal and ethical implications of larger national and global ethics dilemmas. Educators need to further their approach to teaching to be more relevant to the macro and international context of engineering ethics.²⁰

Critical Thinking among Engineering Undergraduates: Today's engineers are required to have creative problem-solving skills and to "evaluate the implications of their solutions beyond their immediate technical context."²¹ Faculty agree that critical thinking skills rank among the top priorities in higher education.²² Yet many faculty may lack a substantive conceptualization of critical thinking and may struggle to teach it effectively.²³ As a result, engineering students do not often graduate with critical thinking skills and the advanced ability to collect, evaluate, and utilize information.²³ These graduates also have little or no experience with dealing in uncertainty and ambiguity in problem solving.

The substantial focus on content in recent decades is a problem across higher education (e.g., Snyder & Snyder²⁴). Too often, curricula place more emphasis on the memorization of facts and the use of well-established procedures than on learning the skills necessary to deal with large, complex problems.²⁵ This trend can be exasperated in an engineering curriculum focused on preparing students for the content of the next class or for the Fundamental Engineering Exam (FE Exam). A broad range of literature discusses the need for these skills to be taught systematically rather than assumed as by-products of an undergraduate education^{26,27,28} and specifically in the engineering classroom.²⁹

Many factors can influence the development of critical thinking skills, in particular prior training and experience. The current trend to include service learning and community engagement as an aspect of engineering education is also being identified as a way to improve critical thinking skills. For example, Graham et al.³⁰ present a multi-year framework for developing critical thinking skills that includes community engagement. Barrington & Duffy³¹ suggest that engineering educators take advantage of the inherent possibilities for developing critical thinking when constructing activities related to service learning. Romkey & Cheng³² identify Engineers Without Borders as one aspect of a framework that includes engineering and society courses and engineering design activities. Although these factors support the student's ability to develop critical thinking skills, appropriate instruction and curriculum design remains a cornerstone of skills development.²⁹

One of the oft-neglected tools for developing critical thinking skills in engineering students is writing. Writing can enhance critical thinking and problem-solving skills, which is especially important when coupled with the fact that engineers in practice report an increasing written communication workload over time.³³ If supervised properly, Wheeler and McDonald report that writing allows students to develop and use critical thinking skills.³⁴ While engineering programs typically incorporate ill-defined problems for capstone projects—another recognized tool for developing critical thinking, writing for reflection will also help develop skills for

problem identification, analysis, metacognition and the formation of value judgements.^{30,35} Snyder & Snyder suggest essay questions rather than simple recall to encourage critical thinking.²⁵

In addition to promoting the development of critical thinking skills, writing is also an excellent tool for measuring critical thinking skills. The unique value of writing in this study is that it allows us to measure both critical thinking and ethical literacy using the same instrument (the persuasive essay).

This Study: The long-term goal of this effort is to develop pedagogical approaches for more effective teaching of undergraduates in how to analyze complex and global ethical dilemmas. In this pilot study, we seek to understand links between underlying critical thinking skills and expressed ethical literacy. Our hope is that understanding these links will provide new insight into means and methods for making ethics instruction more meaningful, more lasting, and more linked to global citizenship.

Methods

Student writing samples on waste electronics were used to explore how undergraduate engineering students feel, think, and propose to act on contemporary global issues related to electrical engineering. These writing samples were gathered from an existing assignment in an introductory class and were not part of an intervention specifically targeted toward improving critical thinking or ethical literacy. The writing samples were treated as a baseline for understanding the quality of ethical literacy and critical thinking that students bring into the classroom prior to any formal ethics instruction, whether elective or required, within the major.

The writing samples analyzed in this study were collected from students at a large public research institution in the Pacific Northwest, classified as Doctorate-granting RU/VH (Research University, very high research activity) and from a moderate size teaching institution in the Midwest, classified as Master's L (Master's Colleges and Universities, larger programs) according to the Carnegie Basic Classification.³⁶ Three different populations of students from the two institutions were studied:

- Public Research 1 (N = 92): these students were enrolled in a large, entry-level electrical engineering course (2011) and were provided with an article on waste electronics, as well as questions/prompts pertaining to the article. Students were then asked to, in exchange for extra course credit, write an essay on the article as guided by the provided questions. The prompts for the Public Research 1 population are nearly identical to those for the Public Teaching 1 population.
- Public Teaching 1 (N = 19): these students were enrolled in a sophomore-level electrical and computer engineering course in 2012 and were also provided with the same article on waste electronics as the other two populations. Questions/prompts regarding the article were provided and students were asked to write an essay as guided by the provided questions. Essays were graded and provided course credit equivalent to one weekly homework assignment.
- Public Research 2 (N = 155): these students were enrolled in the same course as the Public Research 1 population but in a different year (2012). These students were provided with somewhat different prompts (see Instruments section) but the identical waste electronics

article as the other two populations. However, students in this population were not required to use the article in their essays, but were given the freedom to draw on sources most appropriate to their argument as presented in the essay.

In this pilot study, ten essays from each student population were randomly selected for analysis.

A. Research Questions

Three research questions were addressed in this pilot study.

Research Question #1:

What patterns of ethical literacy emerged in engineering student writing?

This research question provides a preliminary understanding of the types of weaknesses and strengths that tend to emerge as students write about macroethical dilemmas. Insight provided by this question can provide insight into both topics and skills that require more emphasis in ethics instruction.

Research Question #2:

What patterns of critical thinking emerged in engineering student writing?

This research question provides an understanding of what deficits in critical thinking may underlie weaknesses in engineering student writing. Such insight can support answering our third research question.

Research Question #3:

How did patterns of critical thinking connect to those of ethical literacy?

This question seeks to differentiate which weaknesses in understanding macroethical dilemmas may be rooted in deficits in critical thinking and which weaknesses may reflect insufficient underlying knowledge about a particular macroethical dilemma. We hope that this insight can help practitioners decide how to spend time in skill-building (critical thinking) prior to introducing macroethics into the curriculum.

B. Subjects and Procedures

Students for this research were all undergraduates in engineering enrolled at either the Public Research or Public Teaching institution. Students at the Public Research institution were recruited from two offerings of an introductory-level sophomore electrical engineering course with a total enrollment of over 150. Students majored in a wide variety of engineering fields, but most students were from bioengineering, electrical engineering, or mechanical engineering. All students in the class were invited to complete the essay and also to release their work for this research. Students were fully informed (verbally and in writing) that no student's grade would be negatively impacted by not providing consent. Details regarding who provided consent and who did not were withheld from the instructor. In total, 101 students in the Public Research 1 group (2011) completed the extra credit assignment and 92 released their work for research. In the Public Research 2 group (2012), essays were assigned for 2% of the total grade rather than for extra credit. Out of 188 students who completed the essay, 155 released their work for research. In the Public Teaching 1 group (2012), essays were assigned as a regular homework (for a grade) in a sophomore-level electrical and computer engineering class. 19 of 22 students completed the assignment and released it for research. Ten samples from each population of students were randomly selected for this analysis.

Complete demographics for the student population are not available for this analysis because several students in the Public Teaching 1 group chose not to complete a corresponding survey associated with this study that contained demographic questions. However, most students in the sample were men and most were Caucasian, with a significant minority of Asian students in the Public Research populations. All essays selected for this analysis were from native English speakers in order to reduce the confounding effects of language proficiency on the analysis.

C. Instruments

1. Assignment

Three highly similar writing assignments were provided to the students in this study. For Public Research 1 students, the writing assignment consisted of three components: a scholarly article, writing directions, and guiding questions. The article students were to read and write about is a 14 page scholarly article by Sepulveda et al. entitled “A review of the environmental fate and effects of hazardous substances released from electrical and electronics equipment during recycling: Examples from China and India”.³⁷ This article discusses the presence of poor waste electrical and electronic equipment (WEEE) recycling techniques in China and India and also discusses the impact these practices have on a variety of stakeholders. Along with the article, students were provided written instructions to write at least one page of text in response to the following prompts:

- 1. What part of Waste Electronics Recycling in Figure 1 concerns you most? Why?*
- 2. From the part of Waste Electronics Recycling process you chose in Question 1, what is the impact on humans? On ecosystems? (address air, water, or food quality as needed)*
- 3. What do you think modern engineers producing these electronic technologies should do as an "ethical" response to the waste electronics recycling dilemma? Comment specifically on how far in scope engineers should go to limit the waste electronics recycling impact.*

Figure 1 of the article outlined possible environmental impacts and pathways to exposure for those working in and around waste electronics processing and recycling facilities.

The writing assignment for the Public Teaching 1 students was identical to that for the Public Research 1 population with the following exceptions:

- The guiding questions contained an additional question in addition to the three noted above: “*What do you think you, as a consumer, should do about WEEE Recycling?*”
- Essays were given a grade rather than extra credit for the course.

Finally, the writing directions and guiding questions for Public Research 2 population were different than the first two populations, although they emphasized the same topic of waste electronics. The writing assignment for the Public Research 2 population was given for a course grade rather than extra credit. Students were asked to write a persuasive essay whose goal was to “convince the reader of a major impact of waste electronics and electronics recycling on society.” Students were asked to focus on one and no more than one of the following: technological, economic, environmental, human health, or ethical impacts of waste electronics. The Sepulveda article³⁷ was made available to students through the class web site but students were free to chose from any sources of 'reputable facts' available to them. Furthermore, an introduction, supporting arguments, counterargument, and conclusion were required in each essay. Essential elements

and a description of what each of these components should contain was also included in this writing assignment.

For all three populations, students were given one week to complete the assignment. Submitted assignments were separated into two groups: those with consent and those without. Essays that had corresponding consent were forwarded to research assistants for evaluation, described next.

2. Evaluation

Ethical literacy was evaluated using five subscores (EL1-EL5) as denoted in Table 1. Each subscore was designed to capture a different aspect of Ethical Literacy, defined for technical communication by Cook³⁸ as the ability to consider relevant ethical standards and stakeholders which are relevant to the ethical dilemma of (in this case) global waste electronics. Each criterion associated with ethical literacy contained a checklist whose items were graded on a 2-item (“Yes” or “No”) or 3-item scale (“Not at All”; “Somewhat”; or “Clearly”). Items within each criterion were then summed and scaled to a maximum score of 100 points. The total Ethical Literacy Score was simply the sum of the five individual criterion scores, scaled to a maximum value of 100. Examples of checklist items under each ethical literacy criterion are included in Table 1.

Table 1: Evaluation Rubric for Ethical Literacy

Subscore	Description	Sample Checklist Item
EL1	The author references appropriate codes of ethical conduct to the analysis of the global waste electronics dilemma.	Does the author state a relevant code of ethics or governing society of engineers?
EL2	The author applies fundamental canons and professional obligations of ethical engineering conduct to the analysis.	Does the author acknowledge that the engineer should strive to adhere to the principles of sustainable development?
EL3	The author considers the human impacts of (and stakeholders in) the global waste electronics dilemma.	Does the author acknowledge that persons of certain occupations are affected by the WEEE* issue?
EL4	The author considers the ecosystem impacts of (and stakeholders in) the global waste electronics dilemma.	Does the author acknowledge that non-agricultural plants are affected by the WEEE* issue?
EL5	The author recognizes agents of change in the resolution of the global waste electronics dilemma.	Does the author acknowledge that governments are able to play a role in resolving the WEEE issue?

* WEEE (Waste Electronics and Electrical Equipment)

Initially, two research assistants evaluated these 30 writing samples using a draft of the ethical literacy evaluation rubric. The evaluation rubric was revised until the two research assistant scores fell within 10% of one another on each criterion to facilitate inter-rater reliability. Before assessing student essays, the research assistants removed all identifying information from essays so as not to bias their assessments. Neither of the research assistants knew the students personally, also minimizing potential for bias in the assessment.

Critical Thinking was evaluated using eight subscores (CT1-CT8) extracted directly from the International Critical Thinking in Reading and Writing Test³⁹ which requires that when critical thinking is applied to writing, the author adheres to the intellectual standards of writing: clarity, precision, accuracy, relevance, significance, depth, breadth, logic, and fairness. Each criterion was assigned a score between 0 and 100 and the 8 criteria were then summed and scaled to a total maximum score of 100 points for the total Critical Thinking score. All (criterion) scores were based on an assessment of Unacceptable or Unskilled (0-20 points), Poor or Minimally Skilled (30-40 points); Mixed Level or Beginning Skills (50-60 points), Commendable or Skilled (70-80 points); or Excellent or Highly Skilled (90-100 points). Samples of how a particular level was assessed within each criterion are provided in Table 2 alongside a description of each Critical Thinking criterion. Critical Thinking scores CT1, CT4, and CT6 were evaluated by two research assistants each and the remaining CT scores by only one research assistant. At this time, inter-rater reliability analysis is in process for the Critical Thinking evaluation rubric.

Table 2: Evaluation Rubric for Critical Thinking

Subscore	Description	Sample Checklist Item
CT1	The author clearly states his or her meaning, and avoids text that is vague, confused, or muddled in some way	<i>Commendable:</i> The essay has only one of the following deficiencies: 1. Poor Introduction. 2. Poor Conclusion. 3. More than one body paragraphs which could be condensed or more than one paragraph which should be separated. 4. Sentence Structure is poor.
CT2	The author is accurate in what he or she claims.	<i>Mixed Level:</i> The essay contains two factual inaccuracies.
CT3	The author is sufficiently precise (providing details and specifics when they are relevant).	<i>Poor:</i> The essay has three major body paragraphs that lack supporting facts.
CT4	The author does not wander from his/her purpose (thereby introducing irrelevant material).	<i>Mixed:</i> Author wanders or strays twice within body paragraphs.
CT5	The author takes the reader into the important complexities inherent in the subject (the writing is not superficial).	<i>Commendable:</i> The essay has only one of the following deficiencies: 1. Facts stated but not linked to thesis. 2. Connections among agents of change are not considered. 3. Politics and government policies are not considered. 4. Corporate barriers to engineers advocating for change are not considered. 5. Fate of environmental toxins is not clearly described.

CT6	The author considers other relevant points of view (and avoids being overly narrow in perspective).	<i>Mixed:</i> Counterpoint is stated and is adequately explained or sufficiently refuted, but not both.
CT7	The text is internally consistent and does not contain unexplained contradictions.	<i>Poor:</i> The essay contains three contradictions.
CT8	The writing is significant.	<i>Excellent:</i> The impact of both the problem and the solution are both clearly expressed and significant/non-trivial.

3. Data Analysis

Evaluation scores were collected and aggregated. Descriptive statistics, including mean and standard deviation (SD) were tabulated for each literacy and critical thinking criterion for the three student populations considered in this study. Because of the small sample size used for this pilot study and due to the fact that our objective is primarily focused on understanding “What?” rather than “How Many?” or “How Different?”, our data were analyzed qualitatively. After identifying certain scoring patterns in the writing sample evaluation both for ethical literacy and critical thinking, all writing samples were coded according to these targeted scoring patterns. Patterns within each writing sample were compared to identify links between the critical thinking abilities of students and their ability to synthesize and articulate macroethical dilemmas. Excerpts that represent each major emerging result from this pilot data are also provided in the results section to provide further insight into what student weaknesses in their writing look like when writing about a major global ethical dilemma like waste electronics.

Results and Discussion

Analysis of statistical significance among different populations in this study was not warranted because of small sample sizes (ten randomly selected samples from each population). However, descriptive statistics for each critical thinking and ethical literacy criterion are provided in Table 3 to provide a general indication of how scores compared with one another across the sample.

Ethical Literacy Scores: Noteworthy among these scores is that all criterion and total scores are very low with a maximum mean score of 40 points out of 100 points for the EL3 (consideration of human stakeholders) criterion and a minimum mean score of 0 points out of 100 for the EL1 criterion. While these low scores are in part explained by the fact that students wrote this essay without formal training in ethical codes or professional responsibilities, this result also clearly speaks to the need for teachers to provide comprehensive instruction to students in how to analyze macroethical dilemmas. In particular, teachers in engineering should reference professional society codes and responsibilities more often in a wider range of classes so that students are more likely to know and reference these obligations when appropriate.

From this pilot study, we also can see that students may not naturally seek out all or even most stakeholders associated with a global problem. Not surprisingly, when it comes to stakeholders, students identify specific groups of people who are affected by waste electronics (EL3) much more readily than non-human stakeholders (plants, animals, agricultural crops, etc.).

Table 3: Descriptive Statistics for Writing Sample Evaluation
(All scores are out of 100 possible points)

Metric	Criterion	Public Research 1		Public Research 2		Public Teaching	
		Mean	SD	Mean	SD	Mean	SD
Ethical Literacy	EL1	0.0	0.0	0.0	0.0	0.0	0.0
	EL2	7.3	2.2	3.5	3.8	8.1	2.8
	EL3	37	15	40.0	26	27	12
	EL4	9	5.7	6.1	6.3	7.1	5.1
	EL5	16	12	9.4	6.8	23	11
	Total	14	5.2	13	6.8	13.0	4.8
Critical Thinking	CT1	75	13	80	14	50	19
	CT2	65	16	58	21	33	24
	CT3	42	11	68	18	32	21
	CT4	74	21	76	15	47	25
	CT5	45	11	46	24	35	22
	CT6	12	6.3	22	23	17	16
	CT7	78	6.0	83	11	70	20
	CT8	50	13	61	15	47	16
	Total	55	7.0	62	9.0	42	14

Critical Thinking Scores: It is noteworthy that students seem to consider a counterpoint (CT6) in their writing only when prompted to do so (as in the Public Research 2 population) and even then, some will not provide a counterpoint or introduce one at a very superficial level. On the other end of the spectrum, students are generally careful in their writing not to introduce contradictions (CT7), although this may be due more to failing to provide sufficient detail (CT3) to allow contradictions than specifically writing to avoid them. The basic quality of writing and use of language (expressed through CT1 and CT4) also tend to be generally good among students, suggesting that deficits in other critical thinking criteria and ethical literacy are a function of underlying understanding rather than use of the English language.

Research Question #1:

What patterns of ethical literacy emerged in engineering student writing?

In analyzing the writing of engineering students in terms of ethical literacy, we observed four distinct patterns emerging from the data (Table 4). The majority of students wrote within the two lowest quality levels of ethical literacy (Level 3 and Level 4). Only one student wrote within the highest level of ethical literacy (Level 1) and five students wrote at Level 2 quality. A short description of each level is provided in Table 4.

Table 4: Common Patterns of Ethical Literacy in Engineering Student Writing

Label	Subjects: N (%)	Description
Level 1	1 (3.3%)	The author provides a balanced treatment of human and ecosystem stakeholders affected by global waste electronics and also considers multiple agents for change involved in the solution to the problem.
Level 2	6 (20%)	The author provides a commendable treatment of human stakeholders affected by global waste electronics, but neglects other stakeholders in the analysis including ecosystems and agents of change.
Level 3	12 (40%)	The author provides a mixed quality treatment of human stakeholders affected by global waste electronics, but neglects other stakeholders in the analysis including ecosystems and agents of change.
Level 4	11 (36.7%)	The author considers all stakeholders in a very limited way and does not consider multiple agents for change.

The single Level 1 student scored the highest among EL3, EL4, and EL5 criteria, but like all students, lacked in EL1 and EL2 (ethical standards and professional obligations respectively). While this student was specific about human stakeholders, he was substantially less clear about non-human (plants, animals, etc) stakeholders and narrow in their consideration of agents of change. For example, this author begins his essay with general statements about human and non-human life alike:

“The big problem arises when cyanide, heavy metals, dioxides and other toxins become bioavailable. Ingesting such toxins devastates plant, animal and human health.” (Public Research 1)

Later in the essay, this author writes more specifically about which groups of people are affected but does not go into further detail about which animals and plants are affected:

“Worker protection is clearly another area of containment that has not been accounted for. Workers are submersed for prolonged periods in a hazardous environment. As respiratory disease is the main threat for workers and bystanders at WEEE recycling plants, air quality needs to be monitored and regulated with a filtration and ventilation system. Proper eye, lung, and barrier protection is vital for all who work at such a place to remain healthy. And, a hazardous workplace is no place for a child.” (Public Research 1)

A Level 2 student spends considerable time outlining the humans impacted by dismantling:

“Dismantling releases harmful chemicals and particles into the air... Dioxins and furans can cause serious damage to people's health. Being exposed to dioxins can increase a person's risk of getting cancer... Other health hazards that are linked to dioxins and furans are damage to the immune system and developmental problems.” (Public Teaching 1)

and also attends to other non-human stakeholders, although superficially, in single sentences:

“Fish and other animals also get exposed to these chemicals.” (Public Teaching 1)

“The particles and chemicals... get into the soil and slow the growth of crops growing in the soil.” (Public Teaching 1)

Although this student seems aware of the multiple impacts of dismantling in Waste Electronics, the lack of detail provided for both humans and ecosystems will make it difficult for the student to explore solutions to this ethical dilemma. Lack of specificity and detail appear frequently as a stumbling block toward deeper understanding of how solutions to decreasing WEEE worldwide can evolve over time.

This lack of specificity was common among students regardless of level. On the other end of the spectrum to Level 1, Level 4 performers considered all stakeholders, human and non-human, in a very general way. For instance, consider the following authors who consistently refer to all stakeholders as ‘environment’ and affected people simply as ‘humans’ or the ‘world’ or ‘you’:

“By improperly separating regular trash from E-waste, they are being forever condemned to a landfill where they will degrade and interfuse with the environment, poisoning it, and eventually poisoning the entire population as well.

By continuing to dump the useless electronics in landfills, it will result in the potential build-up of these chemicals within the environment which, when a critical point is hit, could potentially result in the demise of all humans.

...the current methods of electronic waste disposal, both proper and improper need to be seriously improved if the world is going to have a chance at staying healthy and keeping its environment a safe place for others to live within.” (Public Research 2)

“Bi-products also release wastewater and leachates, it also creates auxiliary substances such as effluents into the water and into the soil. Each of those emissions/wastes hurt the environment in multiple ways that ultimately affect you.” (Public Teaching 1)

Unfortunately, in these writing samples, we see that most students write at Level 3 or Level 4 ethical literacy (24 students or 80% of the population) with very few students achieving a comprehensive consideration of specific stakeholders (5 students at Level 2) and only 1 student showing an ability to consider multiple stakeholders at multiple levels. No students considered ethical codes of conduct (e.g., IEEE) and few considered their professional obligations in consideration of the waste electronics dilemma. However, these results need to be taken in context. None of the students in this study received instruction on analysis of ethical dilemmas prior to writing these essays, nor were they assumed to bring in such knowledge from prior classes. However, we argue that the lack of specific ethics curriculum in the students’ toolbox is not the only issue at work here, but rather an underlying deficit in critical thinking skills also contributes to the lack of resourcefulness in identifying standards upon which these macroethical dilemmas should be analyzed.

Research Question #2:

What patterns of critical thinking emerged in engineering student writing?

In analyzing the data for critical thinking, we found more patterns of writing than in ethical literacy. In critical thinking, students tended to cover all the criteria in their writing, even though these criteria were not explicitly provided in the prompts for the writing assignment. When viewed through the lens of critical thinking, nine distinct patterns of writing were separated into

two major categories: “Acceptable” and “Poor” which are described in more detail in Tables 5 and 6 respectively.

Table 5: Common Critical Thinking Patterns contained in “Acceptable” Engineering Student Writing

Label	Subjects: N (%)	Nature of Critical Thinking Scores	Description of Writing
A+	1 (3.3%)	<i>Excellent Style, Excellent Substance</i>	Commendable or excellent in all areas. Counterpoint is successfully presented at a level beyond the superficial.
A	1 (3.3%)	<i>Excellent Style, Commendable Substance</i>	Commendable or excellent in almost all areas, but counterpoint is either not provided or is presented at a superficial level.
C1	7 (23.3%)	<i>Commendable Style, Overstated Substance</i>	Clear, organized writing style. Broad sweeping conclusions made from inadequate underlying evidence, lack of precision (detail) in describing the problem, and failure to examine the complexities inherent in both the problem and the solution.
C2	11 (36.7%)	<i>Commendable/Mixed Style, Mixed Substance</i>	Reasonably clear, organized, accurate, focused writing which provides precise specifics to support the author’s main point, but does not probe as deeply into the complexities of the problem, the counterpoint, nor the overall significance of the problem or proposed solutions.
C3	3 (10%)	<i>Mixed Style, Mixed Substance</i>	Inconsistently organized and often unclear writing which occasionally provides specifics, explores complexities, and touches on the broader significance of the problem and potential solutions. Counterpoint is presented but not well explored.

Among what was assessed to be acceptable writing, five distinct patterns emerged. Two were patterns of excellence in writing. The topmost level (A⁺) writing was rated excellent in all eight critical thinking criteria including the counter point or counterargument which was both included and skillfully refuted in the essay. Authors who did not provide a counterargument or who did so superficially but nevertheless covered all the remaining critical thinking criteria at an excellent level fell into the A pattern of writing. An example of these higher levels of critical thinking as applied to writing follows:

“The effect of WEEE on the environment, specifically the water and soil in the regions near waste disposal areas, is not based on speculation, but rather concrete evidence of damage that has already been done. A study conducted by the Environmental Assessment Review recorded the emissions from the principal WEEE recycling activities in China and India, where the disposal of electronic waste is minimally moderated. This study brings to light

many concerning by-products of WEEE such as “leachates from dumping activities, particulate matter from dismantling, fly and bottom ashes from burning activities, fumes from mercury amalgamate, wastewater from dismantling and shredding facilities, and effluents from cyanide leaching” (Sepúlveda et al. 2009). Furthermore, the presence of substances such as lead, Polybrominated diphenyl ethers (PBDEs) and Dioxins and furans (PCDD/Fs, PBDD/Fs) has been recorded in significantly higher concentrations in the soil and rivers of Bangalore, India Guiyu, China, Pakistan, and India near waste treating facilities than control samples (ibid).” (Public Research 2)

Below the A level, a distinct gap in overall quality of critical thinking as applied to essay writing emerged. The three C categories detailed in Table 5 tended to contain elements of excellent or commendable critical thinking that were mixed with elements of poor critical thinking. Each of these patterns was different from one another despite the fact that their overall quality was similar (C Level). The first pattern (C1) was readily recognized when the author, while having generally good writing style (commendable), tended to overstate the substance of his or her arguments. In the C1 pattern, insufficient precision or detail was provided to support the magnitude of the argument. For example:

“Recycling workers sift through the mountains of electronic waste searching for metals such as copper, aluminum, lead, zinc, and even many plastics that can be reused. During the recycling process, workers are exposed to heavy metals, such as lead, cadmium, mercury, and chromium and take in toxins from flame retardant chemicals from shredding and disposal (cleanproduction.org). However, the chemicals and toxins don’t stop with the recycling workers at the dump. The electronic waste in the landfills can leach into the soil and groundwater. This allows the heavy metals and toxic chemicals to spread far beyond the confines of wherever they were dumped.” (Public Research 2)

Note that in this essay, the author has constructed an articulate argument for the magnitude of the global electronic waste problem. However, precision regarding exposure levels, relative amounts of toxins, and other details are missing from the argument posed above, as is a more complex examination of how and to what degree these toxins reach soil, water, and other elements far from the source of contamination. These missing elements are key elements of critical thinking and make for a lower score in an essay that is otherwise well written and organized.

The second C level pattern (C2) had the opposite weaknesses to the C1 style. In these essays, authors tended to address the details well, but often did not express the complexities and interrelationships among these details nor the broader significance of the chosen problem (within waste electronics. For example:

“Guiya, China has been on the rise as the “e-waste capital of the world”, where major-consumer countries such as India and the United States ship their unwanted electronic waste, to have workers in unregulated conditions sift through it, searching for any reusable materials or scraps at a profit of \$1.50/hr (Electronic, 2012). Exporting our electronic waste products to seemingly desperate countries is an increasingly common practice, to put it in perspective, shipping a computer monitor to China costs about 10 cents, while properly recycling it costs several dollars (Tarko, 2006). Studies have shown that up to 80%

of electronic waste collected for recycling in the US ends up to being exported to developing countries (Kahhat, 2008).” (Public Research 2)

While this author clearly supports the idea that the United States ships a great deal of electronic waste to China, the author does not point out the significance of this lopsided treatment. In other words, the evidence is not complemented by the significance of that evidence.

No essays that were either inadequate in substance or poor in overall style fell into the “Acceptable” patterns of writing (Table 5). Rather, when either substance or style (or both) were poor, these patterns of writing were assigned to the “Poor” writing category. Details regarding the patterns in this category of writing patterns are summarized in Table 6.

Table 6: Common Critical Thinking Patterns contained in “Poor” Engineering Student Writing

Label	Subjects: N (%)	Nature of CT Scores	Description of Writing
D1	2 (6.7%)	<i>Poor Style, Overstated Substance</i>	Unclear, disorganized writing with multiple inaccuracies but few contradictions. Broad sweeping conclusions made from inadequate underlying evidence, lack of precision (detail) in describing the problem, and failure to examine the complexities inherent in both the problem and the solution. A counterpoint is superficial or absent.
D2	4 (13.3%)	<i>Poor but Consistent Style, Inadequate Substance</i>	Unclear, disorganized writing with multiple inaccuracies but no contradictions. Lack of precision or detail regarding the specific problem and solution discussed go hand in hand with lack of significance outlined for the problem and solution and failure to examine the complexities inherent in both the problem and solution. A counterpoint is superficial or absent.
D3	1 (3.3%)	<i>Commendable Style, Inadequate Substance</i>	Clear, organized writing style with little consideration of supporting evidence or broader significance of the problem. A counterpoint is superficial or absent.
F	1 (3.3%)	<i>Poor Style, Inadequate Substance</i>	Poor at all levels.

The first “Poor” style (D1) was very similar to the C1 style in that the substance tended to be overstated and not backed up by sufficient evidence to merit the author’s claims. For example:

“There are many factors to take into account when it comes to this issue, but the one that seems most worrisome is the fact that WEEE’s can decompose and pollute our ground water. For developed countries, there are facilities and filters that deal with this fairly well,

but in developing, it can lead to very poor health conditions for their populations.” (Public Teaching 1)

The second style in the D category (D2) was very similar to the F pattern except that the author seemed attentive to avoiding contradictions throughout the essay. However, beyond this asset, the author’s writing style was generally poor (critical thinking criterion CT1 and CT4) and the underlying substance supporting the author’s argument was inadequate. Unlike the D1 style, however, the author also did not achieve significance in the writing, avoiding both detail and evidence, and also statements that united the essay into a message of significance. For instance:

“Frequently, many people don’t stop to think about what kinds of hazards are in some of the electronic equipment they throw away on a daily basis. Here in the US, we have a number of different locations to dispose of our WEEE. Stores like Best Buy will take most types of large electrical devices and send them off to be disposed of properly to keep the environment from getting contaminated. The companies that Best Buy then sends the used and outdated electronics to are under strict governmental regulations that only allow a minimal amount of pollutants into the atmosphere.” (Public Teaching 1)

As in the ethical literacy assessments, we see a general lack of advanced critical thinking skills in the writing samples in this study. Over 25% (8) of the students did not express critical thinking skills at a “passing” level in their writing (Table 6). Another 14 students (47% – a combination of C2 and C3 scores) had mixed results where portions of the essay demonstrated commendable critical thinking but a majority of the essay did not. Another seven students (23%) had a commendable writing style but the substance of their essays lacked several measures of critical thinking in the substance of the essay.

Research Question #3:

How did patterns of critical thinking connect to those of ethical literacy?

After we coded each writing sample from this pilot study with an ethical literacy pattern (Table 4) and a critical thinking pattern (Tables 5, 6), we looked at pairs of patterns within each writing sample. The results are shown in Table 7. The first and most obvious trend to note from Table 7 is that lower ethical literacy levels (corresponding to lower quality of ethical literacy) tend to follow lower levels of critical thinking. Some of this result is expected because of a small and unavoidable overlap between the evaluation rubrics. However, this result may also be attributed in part to the fact that students who have only rudimentary skills in critical thinking are also challenged to express comprehensive levels of ethical literacy in their writing. Another possibility is that students did not feel motivated in this exercise to apply their critical thinking skills, which is a serious possibility when it comes to writing for engineering students!

While the connection between lower levels of critical thinking and lower levels of ethical literacy is somewhat expected, a more surprising result in this analysis is the C1 patterns. Students who wrote in the C1 critical thinking style (Commendable Style but Overstated Substance) exhibited a full range of ethical literacy; some C1 students scored at Level 1 ethical literacy while others scored at Level 4. Still others scored within the two levels in between. Clearly, multiple types of students and skills are represented in the C1 pattern. This result may also suggest that some students are relying on style to replace competence in their writing (Style over Substance), while others may be simply highly competent writers who are diligent about attending to all aspects of

a problem when they write, hence applying critical thinking to achieve ethical literacy even without explicit instruction in the area.

Table 7: Relationships between Critical Thinking and Ethical Literacy

Critical Thinking Pattern	Ethical Literacy Pattern	Subjects: N (%)
A+ or A	Level 2	2
C1	Levels 1, 2, 3, 4	7
C2	Level 3	11
C3	Level 4	3
D1	Level 4	2
D2	Level 3	4
D3	Level 3	1
F	Level 4	1

Limitations and Implications

Limitations: In drawing data from small samples at only two institutions, it is not clear whether or not our findings can be generalized. We are also limited by our evaluation rubrics that failed to discern some differences among students. However, this analysis has provided a number of patterns of writing, viewed from both ethical literacy and critical thinking lenses, with which we can code additional samples and in so doing, understand more of the significance and prevalence of certain patterns over others.

Implications: This study has identified patterns with which students apply critical thinking to writing about macroethical dilemmas in waste electronics. The study has shown that underlying deficits in critical thinking may be driving corresponding deficits in ethical literacy whether or not prior instruction in ethics has been provided. While further research is required to better understand the generalizability of the results, the present results speak to the need to teach engineering students how to incorporate critical thinking into their writing and how to apply these same skills to analyzing problems that are ill-structured, multi-faceted, and generally knotty. These results confirm previous studies that show ethics instruction cannot exist in isolated modules in the engineering curriculum. Instead, it must be part of a progression in the curriculum, starting with basic courses, that develop writing and critical thinking skills alongside technical content and analysis, and ending with culminating experiences that apply these skills not only to capstone design but other advanced tasks such as the analysis of macroethical dilemmas.

Concluding Remarks

This paper has presented a qualitative analysis of a random sample of essays written by engineering students at two higher education institutions. For all essays in the study, both critical thinking skills and ethical literacy were evaluated in the writing on the subject of global waste electronics. Results show significant and generalized deficits in ethical literacy and more specific weaknesses in critical thinking. The most common weaknesses in ethical literacy included a failure to identify relevant professional codes of ethics and insufficient attention to professional obligations in consideration of these world issues. Students also had difficulty identifying specific stakeholders and favored human stakeholders over non-human ones. In terms of critical thinking, students struggled to provide sufficient evidence to back up significant claims or to make claims that had significance.

This qualitative analysis has enabled us to develop codes (levels of ethical literacy and critical thinking) that will facilitate analysis of a larger sample of essays using more quantitative analysis techniques. This future work will, in turn, allow us to understand more about what underlies challenges in ethical instruction and student failures to undertake ethical analysis with proficiency. The fact that this assignment was assessed in sophomore level classes rather than junior or senior level classes presents opportunities for development of both critical thinking and ethical literacy in engineering programs.

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