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Assessing a Scaffolded, Interactive, and Reflective Analysis Framework for Developing Ethical Reasoning in Engineering Students

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Abstract

Educating future engineers to effectively reason through complex ethical decisions encountered in the design and development of new technologies is a critical and relevant challenge. However, a coherent framework to analyze ethical issues with emerging technologies has not been widely adopted. Over three years, we developed and tested an innovative approach to teaching ethical reasoning that integrates a reflexive process of evaluation in a cyber-enabled learning environment. We posited that ethics should: be taught as a reasoning process; allow significant interaction between students; and include reflective application of ethical principles as part of a coherent, reflexive framework. To respond to this need, we developed: a) a pedagogical framework for ethics education of *Scaffolded, Interactive, and Reflective Analysis* (*SIRA*) that extends beyond case-based analyses; b) a coherent ethical reasoning approach, *Reflexive Principlism (RP)*, applicable within engineering; and c) four case-based modules, integrating the SIRA/RP approach, with a novel, multimedia learning platform, each deliverable in a hybrid format for stand-alone course or embedded curricular applications.

Previously, we have demonstrated that ethical reasoning scores of engineering students increase significantly as a result of participating in our SIRA/RP courses. In this paper, we explore the research question: "*Which characteristics of the SIRA approach contribute to changes in ethical reasoning*." To assess our framework we designed a SIRA assessment scale that uses student reported ratings of effectiveness of the *scaffolding*, *interactivity*, and *reflective analysis* characteristics of the course. After pilot-testing and refinement, the 12-item scale and sub-scales were found to be highly consistent ($\alpha = .847$). To determine which SIRA characteristics contributed to increased ethical reasoning scores we ran a hierarchical multiple regression analysis with satisfaction and SIRA efficacy scores as predictors. Controlling for GPA, course semester, and native language, we modeled pre-course satisfaction with the quality of ethics education and ethical concepts taught, and the SIRA subscales for scaffolding, interactivity, and reflectivity. The model was statistically significant in predicting ethical reasoning scores, accounting for 32% of the variance in the data. The strongest predictor was the reflectivity component of our framework ($ß=.433$), indicating that reflectivity elements of the course are significantly important to ethical reasoning change. We also analyzed student rankings of activities associated with the learning framework. Findings indicate that our integration of novel multimedia presentations of the case studies and the case study discussions were the two most important activities contributing to engagement, understanding, critical thinking, and guiding decision-making.

These findings suggest that a coherent pedagogical framework grounded in reflexive principlism and emphasizing interactivity and reflectivity can effectively enhance the ethical reasoning of future engineers in a cyber-enabled delivery of just four cases, in as little as eight weeks. We contribute an evidence-based solution to address curricular needs of engineering ethics, and extend understanding of contributing factors to ethical reasoning development.

Introduction

Educating future engineers to effectively handle novel ethical dilemmas they may encounter in their careers, particularly when professional codes are vague, inapplicable, or in conflict, is a critical challenge for a nation that is advancing science and engineering technologies at an ever-increasing rate. Rapid changes in technology are accompanied by novel ethical concerns, and the application of existing codes of ethics becomes blurred or uncertain[10, 51]. Because of the direct involvement of engineers in developing these technologies, there is a growing call for ethics training across engineering disciplines from accreditation boards, professional societies, and societal views for training in ethics across engineering disciplines[2, 31, 54]. However, many engineering colleges do not effectively prepare students to reason through the ethical challenges posed by “grey-area” ethical issues such as those stemming from new and emerging technologies[15], nor do they demonstrate effective development of the higher levels of ethical reasoning necessary for such analysis. Furthermore, evidence indicates that while engineering students experience a wide range of ethics pedagogy, they still have lower levels of ethical reasoning than their peers in other disciplines[22], although some studies suggest that these differences may be accounted for by other variables, such as gender[48]. As a result, there is a glaring need for coherent and effective strategies for developing ethical reasoning in engineering students, particularly in engineering contexts[34, 36].

The inclusion of ethics within the ABET 2000 engineering student outcomes ushered in a sharp rise in incorporating ethics across the engineering curriculum[2], followed by numerous approaches to ethics education. Some of the most common included exposing students to professional codes, moral or philosophical theories, humanist readings, ethical heuristics, or service learning approaches[30]. The use of case studies, one of the most popular approaches for introducing ethics to engineers, was widespread before 2000[27, 30, 46, 61], and is considered by some to be the most effective means of engineering ethics instruction[28]. Reflecting this widespread interest, the Online Ethics Center (OEC) currently provides a centralized location for the sharing of cases and scenarios[32], including more than 300 cases.

A review of the OEC’s website highlights the large number and wide scope of cases that have been developed and implemented by STEM faculty. Harris and colleagues[28] identified two primary types of case studies in engineering: micro-level cases of individuals deciding how to conduct themselves within the workplace, and macro-level cases of decisions regarding the societal context and impact of technologies. While Davis[17] and others have identified more than a dozen other types of case studies all of these have primarily focused on technical issues such as failure analysis, including failures of products, of design, and on decisions related to standard and codes of ethics. Approaching case analysis in these ways does not give significant attention to developing ethical reasoning nor understanding of ethical principles that are necessary for analysis of situations and dilemmas where codes are not yet in place or are in internal conflict. Attempts have been made to increase the effectiveness of case analysis on ethical reasoning through changing the content of the cases[13] or the pedagogical framework of the case analysis[41].

Despite this widespread use of case studies, there is little to no empirical evidence supporting case studies as an effective strategy for developing engineering students’ ethical reasoning[21, 63]. One key exception comes from investigators from the Center for Research on Learning and Teaching at the University of Michigan. These researchers developed a survey to identify curricular practices that were effective in developing ethical reasoning in engineering students. They implemented this Survey of Engineering Ethics Development (SEED) at 18 institutions across the United States, collecting data from nearly 4000 undergraduate students[22, 26]. The findings from their survey indicated college engineering students have been exposed to a high variety and number of ethics-related experiences, both formal and co-curricular, and they rate these experiences highly. However, the authors also found that students with higher ethical reasoning skills are less likely to be satisfied with ethics education[35, 65], and their satisfaction decreased as they advanced through college. The SEED researchers postulated that this inverse relationship could be explained by a discord between the approaches used to solve ethical dilemmas by students with higher level ethical reasoning and common approaches of engineering ethics educational experiences (e.g., exposure to codes or rules only)[30, 33]. Nonetheless, Finelli et al.[22] found that engineering students had a "surprisingly low" knowledge of ethics, and their ethical reasoning scores were at the low end compared to national norms[7]. Because these results came at a time of increased focus on the ethical development of engineering students, the researchers expressed an ongoing and critical need for new strategies to promote engineering students' ethical reasoning.

Background and Theory

We believe that the lack of effectiveness in changing engineering students' ethical reasoning levels is due to the lack of a consistent and coherent ethical reasoning approach that is suitable for responding to ethical issues that pervade engineering practice. We argue that *reflexive principlism* (RP) as an applicable ethical reasoning approach, a view we have elucidated in earlier work[8]. Furthermore, we posit that in order for this principlist approach to become *reflexive* for engineers, engineering educators need an integrated and facile pedagogical framework that can be engaged repeatedly at various locations in an engineering curriculum. In this paper, we describe the characteristics and the efficacy of such an integrated model for enhancing the ethical reasoning of engineers: the SIRA framework. The core elements of this innovative approach are discussed below.

Reflexive Principlism

The SIRA framework relies on a robust ethical reasoning approach in order for students to reason through a series of case studies. The approach we have described as *reflexive principlism*, relies on four core moral principles – beneficence, non-maleficence, respect for autonomy, and justice – as a guiding framework for ethical decision-making within engineering ethics, and serves as a backdrop against which to re-evaluate codes of ethics. Reflexive principlism is based on the ethical principlism developed most fully in biomedical ethics[4] and applied effectively throughout the training of medical students for the past two decades. We recognized the potential for the application of a modified version of this well-established ethical reasoning framework based on the similarities between engineering and medicine, specifically the issues in professional training and in client-centered professional practice. Not only does this modified process of reflective analysis and integrated dialogue require higher levels of ethical reasoning ability through a principlism approach[4], it also reflects the process by which professional codes of ethics are established and renewed[16, 18, 52].

Applying such a set of principles will provide a critically needed framework which provides coherence and depth for resolving ethical issues posed by emerging technologies in engineering. Such a coherent set of common principles can guide moral decision-making, allow for flexibility in our ethical thinking, and provide a backdrop against which to evaluate and reevaluate existing codes of ethics. Without effective ethical reasoning, principles cannot be applied to any and all contexts given their relevant dissimilarities. The fundamental reflexivity between principles and cases demands higher levels of ethical reasoning by students in their attempts to absolve conflicts between principles either from the top-down using principlism or bottom-up by following codes. Reflexivity is only possible by ethical reasoning, a critical skill needed if one is to resolve ethical decisions in “gray areas” of ethical dilemmas.

The SIRA Framework: Scaffolded, Integrated/Interactive, and Reflective Analysis of Cases

In order for case-based pedagogy to be an effective tool to develop higher levels of ethical reasoning among engineering students, we suggest it should be embedded within a coherent framework for ethical decision-making that involves a process that reflects a higher level of ethical reasoning. We posit that an effective intervention consists of ethics being taught as a reasoning process, involve significant interaction between students, and involve reflective application of ethical principles as part of a coherent, reflexive framework.

To meet these requirements, we developed a novel pedagogical framework that involves an integrated approach to engineering ethics, including scaffolded, interactive, and reflective analysis (SIRA) of ethics case studies. We designed the SIRA framework to challenge students to use higher-level reasoning in their analysis of ethical issues through structured learning modules that invite and facilitate interactive dialogue and reflective analysis about professional codes of ethics and moral principles. Integrated with a principlist approach are well-storied narratives, high levels of interactivity using moderated discussions and facilitated debates, and cases with complex content [1, 43] implemented on an established learning cyber-infrastructure. The ultimate goal is for the ethical reasoning approach of *principlism* to become *reflexive* through the continual application of ethical principles over the duration of a semester. Table 1 summarizes the core elements of the approach.

Table 1*: The SIRA Pedagogical Framework*

Structural components	Related characteristics and learning activities
Integration	Integration involves the utilization of multiple approaches to ethics instruction, including case study, codes of ethics, expert technical and ethical opinions, as well as the core ethical theories and principles
Scaffolding	Directions for learning, notes on materials, structured assignments, instructor feedback, questions that guide inquiry, reflective quizzes, and annotated supplemental content
Interactivity	Peer-to-peer learning methods such as in-class discussion, online discussion postings and responses, deliberation and collaborative group case reports
Reflective analysis	Considering, articulating, or defending a position or decision through writing (e.g. online discussion posting; meta-reflections) or verbal (e.g. classroom responding) discourse.

Reflexivity	The internalization of the application of ethical principles and ethical reasoning process after multiple iterations of case analysis

We designed the SIRA framework to work in two learning formats: (a) a hybrid-format that integrated live classroom interactions with a set of online learning modules delivered through a cyber-enabled learning infrastructure; and (b) a completely online format with no classroom interactions. In both formats engineering graduate students first participated in a meta-module on Reflexive Principlism followed by four case study modules developed with the SIRA/RP framework. Each SIRA case module was designed to progress students through a series of six structured and integrated learning stages including: (a) establishing knowledge; (b) perspective taking; (c) compare and contrast; (d) inducing conflict; (e) decision-making and justification; and (f) meta-reflection (see Table 2). For each stage we designed a specified type and delivery of content and learning activity to facilitate the pedagogical process. The structure included higher levels of supportive materials in the earlier stages to assist students in gaining knowledge and confidence in their learning ability. As the learner progressed through the module the degree of scaffolding provided was gradually reduced, the reflectivity was increased, and the interactivity varied dependent on the type of learning specified. The final stage of meta-reflection required the student to reflect on what they had learned about ethical reasoning, specifically about how they made a decision by specifying and prioritizing the four principles within the context of the case. The overall goal of this pedagogy was to increase the level of independent learning, range of perspectives considered, and internalization of reasoning processes in order to challenge the student into higher levels of ethical reasoning.

Table 2*: Structure and Stages of Learning Modules Developed within the SIRA Framework*

Learning stages	Stage 1: Establishing knowledge	Stage 2: Perspective taking	Stage 3: Compare & contrast	Stage 4: Inducing conflict	Stage 5: Decision-making & justification	Stage 6: Meta-reflection
Content:	Case scenario, facts, and expert information	Self and other stakeholder perspectives	Comparing perspectives and principles	Expert ethical and technical opinions	Debate and justification	Reflection on reasoning process
Delivery:	Multimedia – video, images, and text	Online posts	In-class and online posts and responses	Multimedia – video, voice, and text	In-class and group case report	Written responses
Activity:	Watching and reading	Reflective writing and reading	Moderated discussion	Listening and reading	Moderated discussion and collaborative writing	Reflective writing
Scaffolding:	High	High	Low	High	Low	Low
Interactivity:	Low	Medium	High	Medium	High	Low
Reflectivity:	Low	Medium	Medium	Medium	Medium	High

Methods

In testing this pedagogical framework, our research was guided by this fundamental question: *Which characteristics of the SIRA approach contribute to changes in ethical reasoning abilities in engineering graduate students*?

Participants

Sixty-one graduate students (26 females, 33 males, age range: 20-39 years) participated in five courses beginning in Spring 2013 and ending in Spring 2015 (two students did not provide demographic information). Twelve (20%) of the students were international citizens, and 16 (26%) students had a primary language other than English. All but two of the participants were early in their graduate programs, either as students in a professional master's degree program or in the first year of doctoral studies; the remaining two were seniors enrolled in the graduate level course for elective credit. This early phase training demographic was selected because research indicates the initial years of graduate study are an important stage of development of professional decision-making skills. Because the course was offered through the School of Biomedical Engineering, a majority of the participants (61%) were pursuing biomedical engineering majors; other academic areas of study included civil, electrical/computer, industrial, and mechanical engineering. Sixteen students participated in-class (26%) and 45 participated online. In the two summer sessions, all students completed the course asynchronously. However, even in-class students completed the bulk of their classwork online. The primary distinction between the in-class and online groups is that the former participated in a weekly lecture/discussion period whereas the latter did not. Additionally, most of the online students were enrolled in a professional masters degree program, while most of the in-class students were enrolled in doctorate degree programs. Table 3 provides an overview of the participant demographics.

Table 3: *Demographic Characteristics of Participants* (N = 61)

		Pilot		Experimental			Total
		Spring 2013	Smr 2013	Spring 2014	Smr 2014	Spring 2015	
		$n = 20$	$n = 10$	$n = 19$	$n = 5$	$n = 7^*$	$n = 61^*$
Gender	Female	12	5	7	1	1	26
	Male	8	5	12	4	4	33
Engineering major	Biomedical	14	4	13	2	2	35
	Other†	6	6	6	3	3	24
Citizenship	U.S.	16	9	15	5	2	47
	Non-U.S.	4	1	4	0	3	12
Primary language	English	14	8	14	5	2	43
	Other	6	2	5	0	3	16
Course format	In-class	5	0	11	0	0	16
	Online	15	10	8	5	7	45

**Note: Two students in the Spring of 2015 did not provide demographic information. †Other engineering majors included civil, electrical/computer, industrial, materials science, and mechanical.*

Participants were analyzed in two groups: the Pilot group (n = 30) included students enrolled in the Spring and Summer 2013 semesters, and the Experimental group (n = 31) included students enrolled in the Spring 2014, Summer 2014, and Spring 2015 semesters. While the experiences of students in both groups were similar, several changes in the learning modules motivated the division of the analyses. First, we instigated a group case report where students worked through an engineering ethics dilemma pertaining to each case study. Second, in refining the cases and their content we added a number of case videos, most notably several animated videos pertaining to the philosophical basis of reflexive principlism guiding the reasoning process and professionally developed videos of all case discussions with their associated multimedia content. Third, we shifted delivery of the course from the *GlobalHub*™ to the Pearson *OpenClass* learning management system in order to make the curricular content more engaging for students.

Learning Context

We implemented our reflexive principlism-based SIRA framework in a one-credit graduate course in engineering ethics composed of five learning modules. Participants were first introduced to a meta-module on reflexive principlism and ethical theories. In the remainder of the course, students worked through a set of four multi-disciplinary case study modules. Two cases came from previously published literature: *Kansas City Skywalk*[40] and *Tissue Engineered Heart Valve*[44]. The other two cases were developed specifically for this course based on recent and unfolding news stories: *Diagnostic Device for Osteoporosis*[55] and *Deepwater Horizon Oil Spill*[9]. These cases were selected specifically to test the versatility of the SIRA approach with a range of case types, including stages of engineering technology development and implementation, scope of ethical impact, and disciplines in engineering.

The set of case-based ethics learning modules was delivered as a one-credit hour graduate-level course in engineering ethics offered in the College of Engineering at a large mid-Western university over five semesters in three years. The course fulfilled part of a mandatory ethics requirement for engineering graduate students and was offered five times in three years in either Spring (16-week) or Summer (8-week) semesters. The learning modules were delivered in two learning formats: (a) a hybrid format that integrated live classroom interactions with a set of online learning modules delivered through a cyber-enabled learning infrastructure; and (b) and a relatively asynchronous, fully online format with no physical classroom interaction. In the first year, the course was delivered in learning platform for global engineering education called *GlobalHUB*™ based on the NSF-sponsored HUB technology for scientific collaboration[37]. In the following year, as we developed and integrated more interactive video components in the modules, we moved the course to a new delivery platform, Pearson *OpenClass*™.

The *OpenClass*™ platform allowed us to integrate innovative multimedia video formats for content delivery. Working in partnership with *InTheTelling* (www.inthetelling.com), we redesigned the case modules using their *transmedia storytelling* format, to fully integrate module materials in a unique multimedia formats that provided a compelling and engaging narrative for the case modules. The modules were then delivered through the *OpenClass*™ learning platform, which provided support for online interaction and discussion, and tracking of learner progress.

Research Design

We developed and tested the SIRA framework using a mixed methods multi-phase research design[14] (see Figure 1).

*Mixed methods***.** Our data collection and analysis practices were governed by a mixed-methods approach, gathering both quantitative and qualitative data. In a strategy of *concurrent triangulation*[57], we collected data through surveys, class observations, semi-structured interviews, and student assignments to evaluate the efficacy of the SIRA module structure, ethical reasoning development, and to iteratively refine the SIRA assessment tool. We integrated data throughout the analysis and interpretation stages during the pilot semesters, using qualitative data from class observations, meta-reflections and open-ended survey responses after each module to guide and refine our assessments as well as our interpretations of the findings. Following this, our data strategy moved to a *sequential explanatory strategy*[57], with the qualitative data collected following collection of the quantitative data. We integrated the data at the analysis phase, and used the qualitative data to explore the quantitative results in more detail and to explain unexpected results. In the final stage, we integrated the quantitative and qualitative data about characteristics of the SIRA framework and used *triangulation* methods[19] to cross-validate our findings about relationships among the SIRA components and ethical reasoning change.

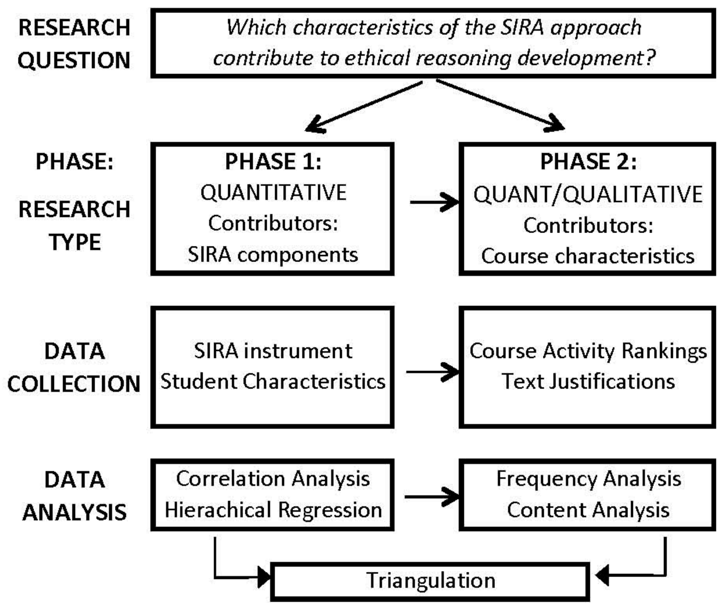

Figure 1: The multi-phase mixed methods research design.

*Multi-phase***.** In the first phase, to understand the contributions of the three components of the framework to ethical reasoning changes, we examined the relationship between ethical reasoning change and the effectiveness of each component using correlation analysis and hierarchical multiple regression modeling. In the second phase, to explore the characteristics of the modules that contributed to its effectiveness, we examined student rankings of course activities, along with their written justifications of why they considered these learning activities to be considered effective, conducting both frequency analysis of the rankings and content analysis of the text. The content analysis findings are presented only briefly in this paper.

Measures

To evaluate the impact of our approach on ethical reasoning development, two assessment tools were administered using a pre- and post-test strategy at the beginning and end of the course. The first tool was the well-validated Defining Issues Test-2 (DIT-2)[49], and the second was the recently developed Engineering Ethical Reasoning Instrument (EERI)[64]. The DIT-2 instrument presents five ethical scenarios, each of which are followed by 12 statements of reasoning related to the ethical dilemma presented. Respondents are asked to rank these 12 statements in terms of their importance, and then select the four most important to making a decision[42]. The EERI instrument was developed to assess ethical reasoning in an engineering context[60, 64], and is structured similar to the DIT-2, but the scenarios are specific to engineering contexts.

Two variables from each test were compared: the P score, which reflects an individual's capacity for postconventional moral reasoning[42], and the N2 score, which starts with the P score and then adjusts it based upon "participants' ability to discriminate between [postconventional] items and lower stage items [personal interest] items"[59] (p. 80). These scores provide quantitative measures of the level of moral judgment of respondents, and higher P and N2 scores reflect more sophisticated levels of complex ethical reasoning ability. To analyze change in ethical reasoning, we conducted a set of paired-samples t-tests to determine whether there were statistically significant gains from the pre- and post- test EERI scores.

To assess and control for explanatory variables that might affect ethical reasoning development, we also collected data on student characteristics, including age, gender, citizenship, academic major, current grade point average, and primary language; satisfaction with prior ethics education, including instruction types and exposure to specific elements of ethics instruction; and characteristics of the course, including semester enrolled and whether or not students participated online or offline.

To measure student satisfaction with ethics education, prior to the course students were asked questions related to their participation in and satisfaction with engineering ethics education. To measure this, we included questions drawn from the SEED survey[22, 24, 26, 35]. From this instrument, we extracted three measures of satisfaction with ethics education: (a) a 6-item scale ($\alpha = .85$) measuring satisfaction with particular kinds of educational activities, such as class discussions, credit courses, extracurricular workshops; (b) a 6-item scale ($\alpha = .91$) measuring satisfaction with particular concepts covered during ethics education, such as being taught about ethical codes, recognizing ethical issues, learning decision-making, and the ability to justify ethical decisions with theory; and (c) a single item measuring general satisfaction with the quality of ethics education received[25].

Procedures

For both groups of participants, all assessments were completed in the first week (prior to module delivery) and final week of the academic semester, using an online survey tool. In the first week, participants completed two one-hour assessments. The first assessment asked participants to complete the DIT-2 survey, followed by the EERI survey. Average completion time for these two surveys was approximately 45 minutes. In the second assessment, students completed a survey about their prior engagement and satisfaction with ethics education. Average completion time for this second set of assessments was about 15 minutes. This set of assessments was repeated in the final week of the semester, but the second assessment surveyed course students about the effectiveness of the course and important learning activities. Average completion time for this assessment was about 15 minutes.

Results

We conducted a set of paired-samples t-tests to determine whether there were statistically significant gains from the pre- and post- EERI scores. The results indicate that students in both the Pilot and Experimental groups showed significant improvements along the EERI measures, with moderate effect sizes in both groups[12]. However, gains measured by the DIT-2 scores were not significant in either the Pilot or Experimental groups. These findings, which we elaborate in other work[1], indicate the SIRA modules were effective in enhancing ethical reasoning as indicated by the EERI assessment.

To address our question regarding the characteristics of the SIRA approach that contributed to changes in ethical reasoning we conducted two sets of analysis. First, we developed and refined a scale containing a set of questions asking students to rate the effectiveness of various structural components of the course as they related to the SIRA framework. Using this scale we assessed the relationships between the perceived effectiveness of three components (scaffolding, interactivity, and reflectivity) of the SIRA framework and ethical reasoning development, using hierarchical multiple regression techniques. Second, we asked students to provide feedback about the course activities they felt were most important contributors to their understanding of ethics, critical thinking, and other learning points. We then examined student rationales for ranking the top ranked course activities, and triangulated these textual data to strengthen our interpretation of the relationship of particular activities to the effectiveness of the scaffolding, interactivity, and reflectivity components of the course. In the following we present and discuss both sets of analyses.

Structural components of SIRA approach that contribute to ethical reasoning change

Student perceptions regarding the effectiveness of specific components of the SIRA modules were captured from a survey administered at the end of the session. In the first course, the survey was administered twice, at midpoint and the end, and data were used to adjust the scaffolding, content, and staging of the modules to optimize student access and comprehension. At the conclusion of each course, we conducted semi-structured interviews to probe additional aspects of student participation, and to elicit dimensions of the modules that were significant to the learning process or to engagement. The interview data provided contextual seeds to revise questions in subsequent instruments.

Scale development. To assess the efficacy of the SIRA framework we designed a scale to measure the effectiveness of the scaffolding, interactivity, and reflectivity components of the SIRA framework. We earlier defined these components in Table 1, and re-summarize them here: (a) the *interactivity* component includes class discussions, online postings, reading and responding to peers' posts; (b) the *reflectivity* component includes writing that requires students to structure their thinking and reflect in a formalized manner; and (c) the *scaffolding* component includes directions on materials, structured assignments, quizzes, and instructor feedback.

We first developed a set of questions designed to probe each construct, asking students to indicate the strength of their agreement with the statement, using a 5-point Likert scale. We used Cronbach's scale reliability tests to assess internal consistency for each scale. Seven variables were combined to form a single scale that measured scaffolding (α = .89), two variables were combined to form a scale measuring interactivity ($\alpha = .59$), and three variables were combined to form a scale measuring reflectivity ($\alpha = .86$). The three subscales were then combined to form a single 12-item meta-scale measuring the effectiveness of the SIRA framework. We piloted this scale during the Spring 2013 semester, probing students during the middle and at the end of the semester. Initial scale reliability tests following this first semester suggested we could improve reliability by eliminating a single item from the reflexivity scale ($\alpha = .89$), resulting in an 11-item scale ($\alpha = .90$). A paired-sample t-test of differences in scale means between the midpoint and the end of the Spring 2013 pilot semester indicated there were no practical or statistical differences in the rating of SIRA effectiveness, suggesting impressions are formed early in the semester. Future probes were made just once at the end of each subsequent semester.

Scale refinement. To refine the scale, we examined item reliabilities, scale reliabilities, and feedback from the interviews and course instructors, and then refined the scale accordingly. After assessing the questions, we refined the wording on two questions, added three new questions, and eliminated four questions from the scale. Specific changes are described below.

- ***Scaffolding subscale.*** In the *Scaffolding* subscale, we eliminated three questions. One question about finding guidance from instructors was eliminated due to low item reliability, and another question about instructor-led discussions was reworded to more accurately reflect ways in which the instructors engaged with the students and then moved to load onto the interactivity construct. A third question about a learning activity no longer relevant to the course was also removed. The new five-item scale had high reliability, $\alpha = .84$.
- ***Interactivity subscale.*** In the *Interactivity* subscale, we also added a second new question about hearing opinions from student peers to reflect a broader variety of ways in which students interact within the course. The new four-item scale had good reliability, $\alpha = .69$.
- ***Reflectivity subscale.*** Finally, in the *Reflectivity* subscale, we examined the scale reliabilities over each of five semesters and found that in three of the five semesters, a question about considering the response of peers prior to posting on discussion boards was internally inconsistent. Removing that item from the scale strengthened the overall consistency of this three-item scale ($\alpha = .66$). Additional inconsistencies were also found in another scale item, but removing this item generated a two-item scale that reduces the opportunity for a strong consistency over multiple iterations. Therefore this item was retained.
- ***Total scale.*** Following these refinements to each subscale, the resulting 12-item question set for the full scale remained unchanged throughout the remaining semesters of data collection. In the final three semesters, this complete 12-item SIRA scale was highly consistent, $\alpha = .85$. Appendix A presents the full set of questions used in this scale, along with means and standard deviations for both the Pilot and Experiment groups. The *Reflectivity* component of the framework was rated highest in terms of effectiveness ($M = 4.13$), followed by the *Interactivity* ($M = 3.87$) and *Scaffolding* ($M = 3.78$) components.

Modeling predictors of ethical reasoning change

Next, to examine the relationships between student satisfaction with prior ethics education, efficacy of the SIRA framework, and ethical reasoning development, we conducted a hierarchical multiple regression analysis to predict ethical reasoning gains in the EERI N2 score from SIRA efficacy scores. To simplify our modeling, we selected the outcome measure from the battery of assessments we conducted that was most significant, which was the EERI N2 score. Previous literature[42] indicates the N2 index is a more robust measure of ethical reasoning, and more likely to reflect changes in a short period of time. We also selected the EERI N2 score, rather than the DIT-2 N2, because the gains were significant in this assessment. There was independence of residuals, as assessed by a Durbin-Watson statistic of 1.707. All other assumptions of linearity, independence of errors, homoscedasticity, unusual points and normality of residuals were met.

To specify the model, we examined the correlation results and literature for theoretically salient variables with either strong variance or predictive relationships with ethical reasoning. Important explanatory variables included gender[9, 58], GPA, primary language[8, 42], citizenship[23, 62], and satisfaction with prior ethics education[65]. A preliminary model was constructed containing all of these explanatory variables but it did not significantly fit the data. We removed the gender, primary language, and citizenship factors. The revised model specification reached significance and accounted for a significant amount of the variance in ethical reasoning changes.

In the first block of the regression, we modeled the explanatory predictors of GPA, whether students enrolled online or offline, and satisfaction with prior ethics education. We created a single composite variable for satisfaction by averaging the values for three measures collected: (a) overall satisfaction with the quality of education received; (b) satisfaction with ethical concepts taught, and (c) satisfaction with types of ethics instruction. Model 1 did not predict changes in the N2 score, $F(3, 43) = 1.91$, $p = .143$, $R^2 = .12$. This means that online presence, current GPA, and pre-course satisfaction did not significantly contribute to changes in ethical reasoning for participants.

In the second block, we controlled for variation in this first set of predictors and then extended the model to include predictors of efficacy of the SIRA approach, entering the three SIRA components: scaffolding, interactivity, and reflectivity. The addition of these three factors to the prediction of N2 score changes led to a statistically significant increase in R^2 of .22, $F(4, 40) = 3.06$, $p = .048$, indicating a much stronger fit to our data. The full model (Model 2) was statistically significantly in predicting changes in the EERI N2 score, $R^2 = .27$, $F(6, 40) = 2.52$, $p = .037$, and Cohen's f^2 was 0.38 indicating a large effect[12]. Therefore, this predictive model fits the data well and indicates 27% of the variance in N2 score gains is explained by these set of variables. Table 4 contains full details for each model.

Furthermore, student satisfaction with prior ethics education, and efficacy of the interactivity and the reflectivity components of the SIRA approach all added significantly to the prediction. The satisfaction predictor ($\beta = -.33$, $p = .022$) was inversely related to changes in the EERI-N2 score, indicating students less satisfied with their ethics education prior to the course were more likely to have more significant gains in N2 scores at the end of the modules. The SIRA-reflectivity scale was a significant positive predictor of changes in the N2 score ($\beta = .38$, $p = .054$), indicating a .38 standard deviation change in rated effectiveness of the reflectivity component generates a full standard deviation increase in N2 score changes. Reflectivity was the most significant positive contributor to changes in ethical reasoning scores. However, the SIRA-interactivity scale was inversely related to changes in N2 scores ($\beta = -.41$, $p = .026$), indicating that interactivity inhibited changes in N2 scores. The perceived effectiveness of the scaffolding components of the course had no significant relationship in predicting ethical reasoning changes for these students.

Table 4*: Hierarchical Multiple Regression Predicting Ethical Reasoning Changes from Online Enrollment, GPA, Satisfaction with Prior Ethics Education, and Efficacy of the SIRA Approach (Scaffolding, Interactivity, and Reflectivity)*

	Ethical reasoning (EERI-N2 change)				
	Model 1		Model 2		
Variable	B	β	B	β	
Constant	77.70		86.03		
Online enrollment[†]	1.12	0.03	-7.52	-0.19	
GPA	-11.37	-0.23	-10.40	-0.21	
Satisfaction	-10.03	-0.26	-12.89	-0.33	*
SIRA: Scaffolding			1.48	0.05	
SIRA: Interactivity			-10.67	-0.41	*
SIRA: Reflectivity			9.18	0.38	**
R^2	0.12		0.27		
F	1.91		2.52		*
R^2 change			0.22		
F for R^2 change			3.06		*

*Note: n = 49, * p < .05, ** p < .01. [†]Online enrollment created as binary variable, coding 0=no, 1=yes.*

Learning Activities in SIRA Approach that Contribute to Ethical Reasoning Change

To glean additional insight from the findings from Phase 1, in the second phase we analyzed two sets of data from the surveys Experimental group students completed at the end of the course: (a) numeric rankings of learning activities, and (b) open-ended justifications of the rankings. We used these qualitative data to interpret the quantitative results in more detail and to explain unexpected results, and then triangulated findings to cross-validate our understanding about the relationships between the SIRA components and ethical reasoning change.

Rankings of Learning Activities

At the end of each course, students were asked to rank the activities that contributed most to their understanding of engineering ethics, critical thinking, decision-making processes, engagement, and provision of new information. We provided participants with a set of 10 learning activities from the modules and asked them to rank the three most beneficial (*1=highest rank*). To analyze these responses, we created a weighted relative frequency of the rankings for each question by assigning three points when an activity was ranked first, two points when it was ranked second, and one point when it was ranked third. The total points for each activity were then divided by the sum of points assigned to the question to generate a weighted relative frequency.

In Table 5 we show the results from the analysis of the Experimental group for each of the six criterion questions. For the questions about ethical reasoning and high engagement, students perceived participating in or watching videos of class discussions or watching the case study videos as the most important activities. These two activities were the highest ranked in these questions. Three activities were among the second tier of rankings, including posting to online discussion forums, reading the posts of others in the online discussions, and required readings. The most surprising insight from this analysis was the low ranking of the meta-reflection activity: few students included this activity in their top-three ranking for any of the questions.

Table 5*: Weighted Relative Frequency Distribution of Top Three Rankings of Learning Activities Deemed Important to Understanding of Ethics, Critical Thinking, Decision-Making, Providing New Information, and Engagement*

	Ethical reasoning			Engagement		Information
	Under-standing %	Critical thinking %	Decision-making %	Most engaging %	Least engaging %	Most new information %
Scaffolding component						
Lectures	7.5	1.7	2.3	2.3	6.4	6.3
Case video	20.1	17.8	19.5	21.3	1.2	32.2
Readings (required)	18.4	14.4	17.2	10.9	1.7	29.9
Readings (supplemental)	1.1	0.6	1.1	0.6	28.3	3.4
Quizzes	0.6	1.1	1.1	4.0	20.8	1.1
Average scaffolding	*9.5*	*7.1*	*8.2*	*7.8*	*11.7*	*14.6*
Interactivity component						
Discussion: Class/Video	23.6	19.0	23.6	24.1	14.5	17.2
Discussion: Reading others	6.9	9.8	11.5	9.8	2.9	5.7
Discussion: Responding	5.7	8.6	5.7	10.3	6.4	1.7
Average interactivity	*12.1*	*12.5*	*13.6*	*14.7*	*7.9*	*8.2*
Reflectivity component						
Discussion: Posting	11.5	17.8	12.6	13.8	4.6	1.7
Meta-reflection	4.6	9.2	5.2	2.9	13.3	0.6
Average reflectivity	*8.1*	*13.5*	*8.9*	*8.4*	*9.0*	*1.2*

Notes. Questions: Which aspects of the course: (a) contributed most to your understanding of ethics; (b) helped you with critical thinking about ethics; (c) best guided your decision-making process; (d) have you found most engaging; (e) have you found least engaging; and (f) provided the most new information. In response to each question, students selected and ranked three activities, using the values 1 = 1st rank, 2 = 2nd rank, and 3 = 3rd rank. Relative frequencies were calculated by reversing these ranks (giving 3 points to 1st rank, 2 points to 2nd rank, and 1 point to 3rd rank), and then calculating the total points assigned to each activity, and dividing this by the total points possible for each question. Average frequencies were calculated by averaging the weighted relative frequency for all activities within each SIRA category, to yield a normalized frequency for comparative purposes.

Finally, to understand how the activity rankings relate to the structure of the SIRA framework, we calculated the average weighted frequency within each of the three categories to provide a normalized frequency that would allow us to compare rankings across the three categories (see Table 5). In terms of important contributors to critical thinking, *reflectivity* activities, specifically engaging with the perspectives of others either in-class or through the discussion forum, were rated highest by the students. In this category, posting responses to the discussion prompts online was considered one of the most important. However, interactivity activities were important contributors to critical thinking as well. *Interactivity* activities were considered the most important contributors to guiding decision-making and understanding ethics, and were also considered the most engaging of activities. In this category, class discussions were considered the most important activity. Finally, *scaffolding* activities were ranked highest in contributing new information, but were also considered the least engaging. In this category, the case study videos and required readings were the most important activities.

In summary, scaffolding activities are most successful in providing new information. Successfully engaging students is generally perceived from interactive activities, as well as the use of video media for course materials and activities. Finally, reflective and interactive activities are perceived by students to be the most important in contributing to critical thinking, decision-making, and the understanding of ethics – elements fundamental to enhancing ethical reasoning. In fact, triangulating these data with the findings from our regression model (Table 4), which indicated that interactivity and reflectivity components of the SIRA framework were the most significant contributors to positive changes in ethical reasoning levels, provides a successful cross-validation of our findings.

Discussion

We posited that to be effective in changing ethical reasoning, ethics education should be taught as a reasoning process, involve significant interaction between students, and involve reflective application of ethical principles as part of a coherent, reflexive framework. To examine this, we introduced the reflexive principlism paradigm for enhancing ethical reasoning in engineering students, along with a novel pedagogical framework of scaffolded, interactive, and reflective analysis (SIRA) of four diverse cases, and then tested this framework over the course of three years in a set of one-credit graduate courses offered through the College of Engineering. Our findings provide empirical evidence that this reflexive approach and pedagogical framework significantly improves ethical reasoning in graduate students. Furthermore, our predictive model and analysis of student rankings, substantiates our position that effective changes in ethical reasoning require significant interactive and reflective learning activities.

The effectiveness of the reflectivity and interactivity components of the SIRA framework significantly predicted increases in ethical reasoning scores. The interactivity attributes of the modules, including in-class and online discussions among peers, was a significant contributor to increasing ethical reasoning in participants, although the effects were mixed (both positive and negative contributors). Research has suggested that moral judgment can be influenced by exposure to rich social contexts[20] as well as curricular interventions[42], and may develop best when individuals have the opportunity to engage in discourse (including argumentation) about moral dilemmas[39]. Similarly, Hartwell[29] has indicated that student-centered moral discourse is one of the most successful curricular strategies. Our findings support this research, although there are mixed results in terms of interactivity in our data that need further examination.

The reflectivity attributes of the modules, including writing meta-reflections, posting reflective responses to online discussion questions, and considering the reflections of other students (with different perspectives), were significantly important in increasing ethical reasoning. Reflective capacity is considered by many to be essential for professional competence, and activities that promote reflection are increasingly used in curricular innovations[56]. Much of the research regarding the use of reflective practice to deepen learning stems from the work of Schon[53], who introduced the notion of building professional competence through *reflection-in-action*. Schon emphasizes the importance of reflective activities as a means to recognize, experience, and build knowledge about professional practice through knowing-in-action. However, empirical evidence regarding effective approaches to reflectivity is not well developed. Extending beyond cognitive models of ethical reasoning, new literature proposes a neurocognitive approach to ethical decision-making[50] by integrating research on how the brain interprets and acts upon its environment. This model couples ethical reasoning as a higher-order reasoning process with reflexive pattern matching, extending theorizing about ethical reasoning beyond cognitive models to account for contributing factors such as empathy, intuition, and retrospection[50]. Our evidence of relationships between reflective activities, reflexive practice, and more sophisticated levels of ethical reasoning provides strong empirical support for extending theories of ethical reasoning in important ways.

That the scaffolding component of our SIRA framework did not significantly predict ethical reasoning change was surprising, given that scaffolding is an important pedagogical goal in learning science. However, even in learning activity rankings, scaffolding activities were not considered important contributors to ethical reasoning or engagement. An exception to this was the very high rating of case study videos, which were considered essential by many of the participants in the study. It is possible that there are limitations in the construct validity of the scaffolding component scale, and this is an area that needs further study.

In summary, our approach first establishes a clear philosophical grounding for the discussion of ethical dilemmas, including an ongoing consideration of multiple perspectives and prioritization of ethical principles, and then introduces a scaffolded, interactive, and reflective pedagogical structure to guide students through case-based considerations of ethical dilemmas in engineering contexts. Integrating these two elements provides the opportunity for significant increases in ethical reasoning in graduate students even in an abbreviated 8-week, one-credit course that can be delivered in online or hybrid formats.

Contributions and Implications

Despite the widespread use of case studies for ethics education in engineering, there has been little empirical evidence supporting case studies as an effective strategy for developing engineering students' ethical reasoning[21, 63]. Furthermore, the literature focusing on ethical reasoning development in engineering students remains limited, with few studies providing empirical evidence of effective educational interventions for engineering students. Our research provides an important contribution to research on ethics education in engineering contexts, and specifically for ethics education in graduate student populations.

Building upon research in ethics, moral psychology and engineering education, these highly interactive and modularized learning modules have broad implication for being embedded into a wide variety of courses and curricula across engineering disciplines, and at undergraduate, graduate, and post-graduate levels. Through our development of new measures to assess the efficacy of ethics education, we have provided evidence of the effectiveness of the principlist approach in engineering ethics education contexts. In addition, we provide a research-tested framework for cyber-enabled ethics learning that has applicability to graduate, undergraduate, and professional ethics education needs around the world.

Limitations and Future Research

There are limitations to this study that we acknowledge. First, our sample size for the participants included in this research is limited and larger samples could potentially reveal relationships among the factors considered that were not evident in our findings. However, the significant and moderately large effects found in our analysis of the framework efficacy yield confidence in the generalizability of these findings. Second, evaluating the effectiveness of the SIRA components through student rating scales rather than learning outcome metrics limits our generalizations to student perceptions of effectiveness of the pedagogy. Third, the inverse correlation of ratings of the interactivity components of the SIRA framework and online participation indicates that the online elements of interactivity could be improved in our learning modules. Students in both offline and online versions of the course interacted primarily through an online medium – discussion was organized in the learning management system platform, and group collaborations were organized by use of asynchronous collaborative technologies like Google Docs. We also provided taped copies of in-class discussions to provide a simulated (yet passive) observation of guided debates of ethical issues. These were perceived well by the students, but were not perceived to be as effective as real-time in-class discussions. This indicates an important area for future research to better understand the processes of interactivity in online contexts and their role in critical periods of ethical reasoning development. At the same time, our predictive model indicated an important negative relationship between the perceived success of interactivity and ethical reasoning development which points to a promising area for improvement both in the design of our learning platform, and in understanding why those who rated interactivity low were more likely to have higher ethical reasoning gains.

Conclusion

In conclusion, our empirical findings indicate that an integrated pedagogical framework grounded in reflexive principlism and emphasizing interactivity and reflectivity can be effective in enhancing ethical reasoning of engineers even when delivered online, for one credit, in as little as eight weeks. We contribute a research-driven solution to address engineering ethics curricular needs, and extend understanding of factors that contribute to ethical reasoning development.

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Appendix A: *Means and Standard Deviations for SIRA Scale Items*

Scale	Item	Pilot (n = 30) 2013		Experiment (n = 31) 2014 - 2015		Combined (n = 61) 2013 - 2015	
		Mean	SD	Mean	SD	Mean	SD
Scaffolding		3.54	0.74	3.94	0.47	3.78	0.61
SCA01	When I have questions, I am able to find the resources I need on the [LMS] system.	3.20	0.89	3.87	0.76	3.61	0.87
SCA02	When I had questions about the course, I was able to find the support or feedback that I need from the instructors.	3.70	0.73	4.19	0.60	4.00	0.69
SCA03	When the material is challenging, I am able to find the resources I need on the [LMS] system.	3.25	0.79	3.71	0.74	3.53	0.78
SCA06	When the material is challenging, I am able to find the support or feedback that I need from the instructors.	3.75	0.79	3.97	0.66	3.88	0.71
SCA07	The structure and presentation of the materials helped to guide my development of ethical reasoning.	3.80	1.06	3.97	0.66	3.90	0.83
Interactivity		3.71	0.53	3.49	1.07	3.87	0.81
INT01	The feedback I receive from my classmates helps my learning of ethics.	3.50	0.55	3.58	0.77	3.57	0.73
INT02	My opportunities to participate in discussions were sufficient.	3.83	0.41	3.71	1.37	3.73	1.26
*INT03	The discussions led by the instructors help my learning of ethics.	3.33	1.03	4.06	0.77	3.95	0.85
*INT04	Hearing the opinions of others helped my general learning of ethics.	4.17	0.75	4.26	0.63	4.24	0.64
Reflectivity		4.50	0.41	4.05	0.61	4.13	0.60
REF01	I read many of the postings of my fellow students (on the blogs).	4.50	0.55	3.77	0.88	3.89	0.88
REF02	Reading the postings of my peers helps me to see a different perspective.	4.67	0.52	4.19	0.70	4.27	0.69
*REF04	Seeing the class discussions helped me to see different perspectives.	4.33	0.82	4.19	0.75	4.22	0.75
Composite scale (12 items)				3.96	0.64	3.96	0.64

Note: Responses measured using a 5-point Likert scale, with 1 = strongly disagree and 5 = strongly agree. LMS = learning management system (GlobalHUB was used in 2013; OpenClass in 2014-15). Item marked with "" added during Summer 2013 semester, therefore data not available for Spring 2013 semester.*