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Development of a Learning Module to Teach Chemical Engineering Students About Moral Reasoning in the Context of Process Safety

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Abstract

Incorporating ethics and ethical decision-making into the chemical engineering curriculum has always been a challenge given that much of this theory is covered outside of engineering, usually in philosophy departments. Nevertheless, moral reasoning has been a component of ABET evaluations for years which means that we need to identify how we can teach and assess the relevant components. Recent work by chemical engineering educators identified an approach to assess student understanding of moral reasoning through the development of the Engineering Process Safety Research Instrument (EPSRI); however, given that many chemical engineering students have not completed a course in ethics or moral reasoning it has not been easy to implement the tool. The goal of this project was to develop a learning module to teach students about different approaches to moral reasoning and ethical concepts associated with these approaches to better prepare them for careers in which they can (and most likely will) encounter supervisors and co-workers who use different moral frameworks and exhibit varying stages of moral development. Indeed, one objective of the module is to help identify sources of moral disagreement. The module was developed by an interdisciplinary team consisting of a chemical engineer and two philosophers that incorporated elements from both disciplines to educate senior chemical engineering students about moral reasoning, using Kohlberg's Stages of Moral Development, and major ethical theories in the context of process safety. The two-day lecture consisted of the students first completing the EPSRI to obtain baseline data on moral reasoning followed by two interactive lecture periods given by the team. At the end of the second lecture period the students took the EPSRI again so that the authors could determine if their understanding of moral reasoning changed after the learning module. A unique feature of this module was the team-teaching approach where students were exposed to both engineering and philosophical concepts allowing them to gain a greater perspective on how moral reasoning could alter a person's engineering design decisions.

Introduction

Ethics and ethical decision making are essential skills that serve as the foundation for ethical and safe engineers. The importance of ethics and teaching ethics to chemical engineers has been acknowledged in the Criteria for Accrediting Engineering Programs (ABET) [1]; however, many departments find it challenging to teach and assess students' mastery of these abstract concepts. There have been several published works by researchers looking into how to incorporate ethics into the classroom [2] including case studies in the unit operations laboratory course [3] or the chemical reaction engineering course [4]. The most common approach has been to incorporate learning modules on ethics in the context of process safety [5]. The way in which process safety is taught to students depends on the department (and university), with some schools having a dedicated process safety course while others teach it as part of the senior design course. Teaching students about the concepts of ethical decision making in the context of process safety makes sense from an educational perspective, in part, due to the ongoing efforts to instill a culture of safety in all young chemical engineers [5]. Through informal discussions with students, the authors observed that students generally had difficulty understanding why some engineers made poor decisions with respect to process safety that ultimately led to catastrophic events, as well documented by the US Chemical Safety Board (crb.org). These decisions often strike students as obviously wrong, and therefore the case studies do not seem like anything they can learn from with respect to moral reasoning. It is difficult for them to see that these decisions might be the result of certain patterns of thinking, or structural stressors, that are likely to affect them in their own professional lives. Incomplete understanding of how and why engineers make bad decisions may stem from receiving insufficient training in moral reasoning. The normative concepts that we use to reason through ethical issues are rarely incorporated into core chemical engineering curriculum and are instead taught in courses offered by philosophy and other humanities departments. Many engineering students may not encounter these courses, depending on which general education courses students elect to take (or take as part of their degree requirements). As such, there is a need to find ways to introduce these concepts into chemical engineering courses through the development of modules to be incorporated into core courses like process safety or senior design.

Once courses incorporate the components of ethical reasoning, educators face the challenge of how to assess students' moral reasoning and understanding of these concepts. A recent study by Butler and colleagues developed an instrument called the Engineering Process Safety Research Instrument (EPSRI), which was designed to "assist in measuring how chemical engineering students make process safety decisions" [6]. This instrument is rooted in Kohlberg's moral development theory that describes the development of a person's moral reasoning through three stages: pre-conventional, conventional, and post-conventional thinking [7]. Roughly, as one moves through the stages of moral development, one is learning how to reason morally by learning how to apply moral principles. A person at the pre-conventional stage reasons in terms of personal benefit and makes decisions primarily on gaining rewards and avoiding punishment, often with little thought given to norms, values, and principles. At the conventional stage, one reasons primarily in terms of professional codes, laws, social norms, and conventions. Finally, at the post-conventional stage, one reasons in terms of ethical principles, values, and in general can give explanations for why something is right or wrong. The theory is neutral on what values or principles are correct, so reasoners at any stage may disagree about what should be done if they disagree about the principles.

The instrument was developed and vetted by industry professionals to include five prompts (called dilemmas in the instrument) related to scenarios that practicing chemical engineers could encounter. Each dilemma lays out a scenario and then the student must decide on an outcome. For example, one dilemma has students choose a material for a piece of equipment that is either (*i*) expensive (and safer and lasts longer) or (*ii*) inexpensive (and less safe and lasts for a shorter period). The student states their preference for the dilemma outcome (either option A, B or cannot decide), and then they respond to ~9-11 follow-up questions where the student ranks the importance of each question (from great importance to not important) in their decision making. For example, one question from the above dilemma asks students to rate the importance of potential safety risks to the employees regarding the choice of the material. These follow-up questions were designed based on Kohlberg's three stages of development as a quantitative metric to gauge the students' stage of moral development. We refer to the reader to the Butler paper [6] for a greater discussion on the instrument and its development. The work by Butler nicely summarizes the development of the instrument and how it could be used to gain a greater understanding of how chemical engineering students' reason through process safety decisions;

however, the instrument did not provide any additional training for the students on the complex ethical concepts associated with moral reasoning.

The goal of this work was to address both challenges (how to educate the students and how to assess their understanding/mastery of ethical concepts) through the development of a two-day learning module. A strength of the proposed module was that it was developed (and implemented) by an interdisciplinary team consisting of a chemical engineer and philosophers that incorporated elements from both disciplines to educate senior chemical engineering students about ethical reasoning, Kohlberg's Stages of Moral Development, and major ethical theories in the context of process safety. A focal point of the module is the use EPSRI as a method to assess the effectiveness of the module as a pre- and post-intervention on the teaching module. This paper summarizes how the module was developed and provides initial findings from the first delivery of the module in the spring 2023 semester in senior chemical engineering design course.

Module Design

The development of the module was part of a larger effort at Louisiana State University (LSU) through a grant from the Louisiana Board of Regents to incorporate ethics into STEM courses. As part of the grant, the authors attended a series of workshops to provide training and education on integrating ethical training and moral literacy into STEM curricula. As such, the design of the module was accomplished during the fall 2022 and spring 2023 semesters with the roll-out of the module near the end of the spring 2023 semester. Several challenges were addressed during the development of the module including: (*1*) what component concepts of moral literacy should be incorporated, (*2*) how to get engineering students invested in learning more about ethics generally, and (*3*) how to assess their mastery of these concepts. Ultimately, the authors decided to first determine how to assess students' understanding of moral reasoning and then build the module around the assessment tool. To accomplish this, we utilized the EPSRI in the form of a pre- and post-survey where the students would first fill out the instrument prior to receiving any instruction. Then they would receive a lecture from the authors (as described below) followed by filling out the instrument again to see if their responses to the given dilemma (or follow-up questions) changed based on a better understanding of moral reasoning. The authors decided to offer the module to second semester senior chemical engineering students in the capstone senior design course (CHE 4172). While process safety is taught at LSU as a junior level course, we felt that the module was better suited to a senior level course. However, based on the results described below we believe that this module could be implemented in either a junior or senior level course. An added benefit of teaching the module in the design course is that the course had both a lecture period and lab period, so the module was developed to be given over two days – during the 50 min lecture on day 1 and during the 80 min lab on day 2. This allowed sufficient time for the pre- and post-surveys and the instructional module.

Once the assessment and method of delivery were determined, we next set-out to develop the module itself. We identified four learning objectives for the module:

1) Students will be able to self-assess their ethical reasoning skills using of the moral development instrument.
2) Students will be able to distinguish between pre-conventional, conventional, and post-conventional moral reasoning.

3) Students will develop their moral sensitivity, moral imagination, and ethical reasoning skills.
4) Students will be able to apply basic concepts from four major ethical theories.

The module itself was developed using a ‘note with blanks’ model and included a combination of activities coupled with traditional lecture (**Figure 1**). On Day 1, after completing the pre-survey EPSRI students were challenged with a small group discussion to answer the prompt “*why are ethics important for chemical engineers*”. The idea behind this activity was address the second challenge identified above – how to get engineering students invested in learning about ethical concepts and practicing the skills of moral literacy. We observed informally through the module that the students became more invested in abstract concepts like justice or obligation when they were grounded in commonly seen facets of chemical engineering. This active learning exercise challenged students to identify the link between process safety and ethical decision making and provide a context for why they should care about ethics. After this, the module included a traditional lecture on concepts including an introduction to ethical reasoning and normative vs. descriptive arguments.

EPSRI Instrument and Kohlberg’s Stages of Development

The EPSRI instrument you took is based on a certain model of good normative reasoning. It is called ***Kohlberg’s Stages of Moral Development***. It is a psychological model that aims to classify what level of moral reasoning someone is capable of, or at what stage of moral development they are. There are three stages based on the reasons one uses to decide on:

This is a ______________________________, which means the highest stage, the post-conventional, is seen as better or more complete than the earlier stages. It is not a matter of having different reasoning styles, but of whether or not someone has achieved mature ethical reasoning.

Here are the stages:

In the **Pre-Conventional Stage**, someone makes their decisions based mainly on either avoiding punishment or on perceived personal benefit. They follow the rules because otherwise they will face some sort of harm or reprimand, or because they will be given a reward. While these are indeed norms one can follow to make decisions, this is the lowest stage because someone in this stage does not have any real understanding of *why* something is good or bad and they are motivated to follow norms entirely by an outside force. They are merely following an authority capable of punishing or rewarding them. They often do not understand themselves as a moral agent.

ACTIVITY #3. What are some cases where someone does something to avoid personal harm or to gain a reward where we would think that action was bad or morally wrong?

In the **Conventional Stage**, someone makes their decisions based mainly on the rules or conventions of one’s society, profession, or other group they are a part of. For example, if someone makes ethical decisions based entirely on a professional list of best practices or a professional code of ethics, they are in the Conventional Stage. Here a person will have a sense of themselves as a moral agent, and wants to be seen as good by others, not just rewarded by them. They may also have a sense that things go better when people follow the rules. This is an improvement from the first stage because a person in the Conventional Stage has an internal sense of motivation for doing good things, and for doing good things for their own sake. However, they also do not have a deep understanding of *why* something is good or bad.

Figure 1. Example of the ‘note with blanks’ model used to the deliver the module.

Day 2 began with an in-depth discussion on Kohlberg's Stages of Development that was led by the faculty member from the philosophy department. This traditional lecture was followed up with two active learning discussions surrounding two prompts: "*what are some cases where a group's conventions are morally wrong*" and "*what are some cases where someone's principles may lead them to do something wrong*". Both prompts were presented in the context of Kohlberg's Stages of Development to get the students to think about why someone would act (or do something) that observers/others would subsequently judge to be ethically compromised. Kohlberg's model suggests that people act in ways that others judge to be ethically deficient because of their stage of ethical development. These prompts were framed in the context of working with different personalities in a plant. For example, someone in the pre-conventional stage could make an ethically questionable decision (e.g., to ignore the discharge of pollutants into a river outside EPA guidelines) if it meant that they could personally benefit from the decision. The discussion linked different decisions an engineer could make in the plant setting with respect to process safety to the Kohlberg's stages of development. This discussion continued into another active learning exercise where the students re-read one of the dilemmas from the EPSRI and then had a discussion on potential motivations for why an individual would make a choice (e.g., not how they, the student, would act, but how and why a hypothetical person would act). The idea behind this exercise was to provide some context towards the instrument so that the students could see the link between the dilemmas, the follow-up questions, and the different stage of moral development associated with each of the questions.

This discussion was followed with an additional traditional lecture on moral reasoning, ethical theories, and moral literacy. The idea behind this part of the module was to provide students with training on different approaches to moral reasoning and how and why some individuals make decisions. For example, we presented the concept of moral sensitivity in the context of how an individual determines which charity to donate money to. Following this, the students participated in another active learning exercise in the context of another of the EPSRI dilemmas. This time the students discussed which aspects of the dilemma were morally relevant, what were some potential outcomes from the dilemma, and what would be the base course of action, normatively speaking. This discussion was mediated by the philosophy faculty member to provide a link (and some context) between a practical application related to process safety and the more complex theory of moral literacy. The module ended with a discussion on major ethical theories (e.g., utilitarianism, care ethics) and how many situations cannot have a clear right or wrong answer because values and principles that guide action are pluralistic and highly context sensitive. Finally, the students completed the EPSRI again as the 'post-assessment'. The learning module can be accessed at the following link for anyone interested in using it - https://www.lsu.edu/ethics/files/modules/moral-development-in-chemical-engineering-module.pdf.

Results

Given that the complete EPSRI has not been made publicly available, we cannot include the specific details for each of the dilemmas or the follow-up questions associated with each dilemma related to factors there were important or unimportant with respect to the students' response. However, to provide some context for the observed results from the pre- and post-assessment, we are including a summary of each dilemma in **Table 1**. Students were asked to choose between option (***A***) and option (***B***) as listed in **Table 1**. Note that for each dilemma students also have the choice of selecting a third option of 'cannot decide' on a course of action.

Table 1. Summary of dilemmas including in the EPSRI [6].

Dilemma 1	Student must choose between two different materials for a piece of equipment handling a hazardous chemical: (***A***) one that is inexpensive but needs to be replaced regularly and has the potential for failure or (***B***) one that is more expensive, lasts longer, and has a reduced risk of failure.
Dilemma 2	Students are challenged with preparing a chemical plant during an impending weather event. They must choose between (***A***) leaving it empty or (***B***) asking for volunteers to monitor sensitive equipment.
Dilemma 3	Students are challenged with a piece of equipment that appears to be malfunctioning; however, nothing appears to be wrong at the time. They are asked to either (***A***) report the incident or (***B***) ignore it.
Dilemma 4	Students are challenged with a piece of equipment that is not working correctly. A co-worker recommends that they modify the equipment outside of normal guidelines. They must choose between (***A***) ignoring the co-worker and speaking to a supervisor on the best course of action or (***B***) modifying it based on the advice of the co-worker.
Dilemma 5	Students must choose between (***A***) exploring alternatives chemical additives to an established process that are less harmful to the employees working with them (although it has not been confirmed by the EPA) with the caveat that exploring for this new alternative could hurt production or (***B***) using the established chemical additive that has potentially harmful outcomes.

The pre-survey was given to 34 students while the post-survey was given to 38 students because four students missed class on day 1 but attended class on day 2 during the spring 2023 semester. Student responses were collected for all five dilemmas and all follow-up questions from the EPSRI. To account for the different total number of students between the pre- and post-survey, we are reporting the students' responses as percentages (relative to the total number in class on each day) instead of raw numbers to allow for a comparison between the pre- and post-surveys. Moreover, no statistical analysis is allowable at this time given that the module has only been given once.

As shown in **Figure 2**, we did not see a substantial difference in the students' response to the prompts for dilemmas 1, 3, or 4. We suspect that the students' response to these three prompts did not change as they are problems that are more technical in nature and relate to following established standard operating procedures or adhering to established safety guidelines including the motivation for selecting a safer material (dilemma 1), reporting potential safety violations (dilemma 3), and not tampering with equipment (dilemma 4). Interestingly, we did see a shift in their response for both dilemmas 2 and 5. For dilemma 2, we observed a shift from 12% to 24% for option A, 21% to 16% for cannot decided, and 67% to 61% for option B (for pre- and post-survey responses respectively). For dilemma 5, we observed a shift from 79% to 92% for option A, 12% to 3% for cannot decide, and 9% to 5% for option B (for pre- and post-survey responses respectively). We suspect that these two dilemmas resulted in a larger change between pre- and post-survey due to the fact that their response to each dilemma is linked to an improvement in the students' normative reasoning skills. Dilemma 2 poses a question of putting colleagues in a potentially dangerous situation to benefit the company. Dilemma 5 poses the question of what is more important: the safety of the workplace versus the bottom line for the company. The change in both can be seen as moving from thinking in terms of benefit (Kohlberg's pre-conventional stage) or acceptable professional practices (the conventional stage) to the terms of values and ethical principles (the post-conventional stage). Given the link to Kohlberg's stages of development, it would appear as if the learning module succeeded in providing students a greater understanding of moral reasoning which was reflected in their responses to certain dilemmas.

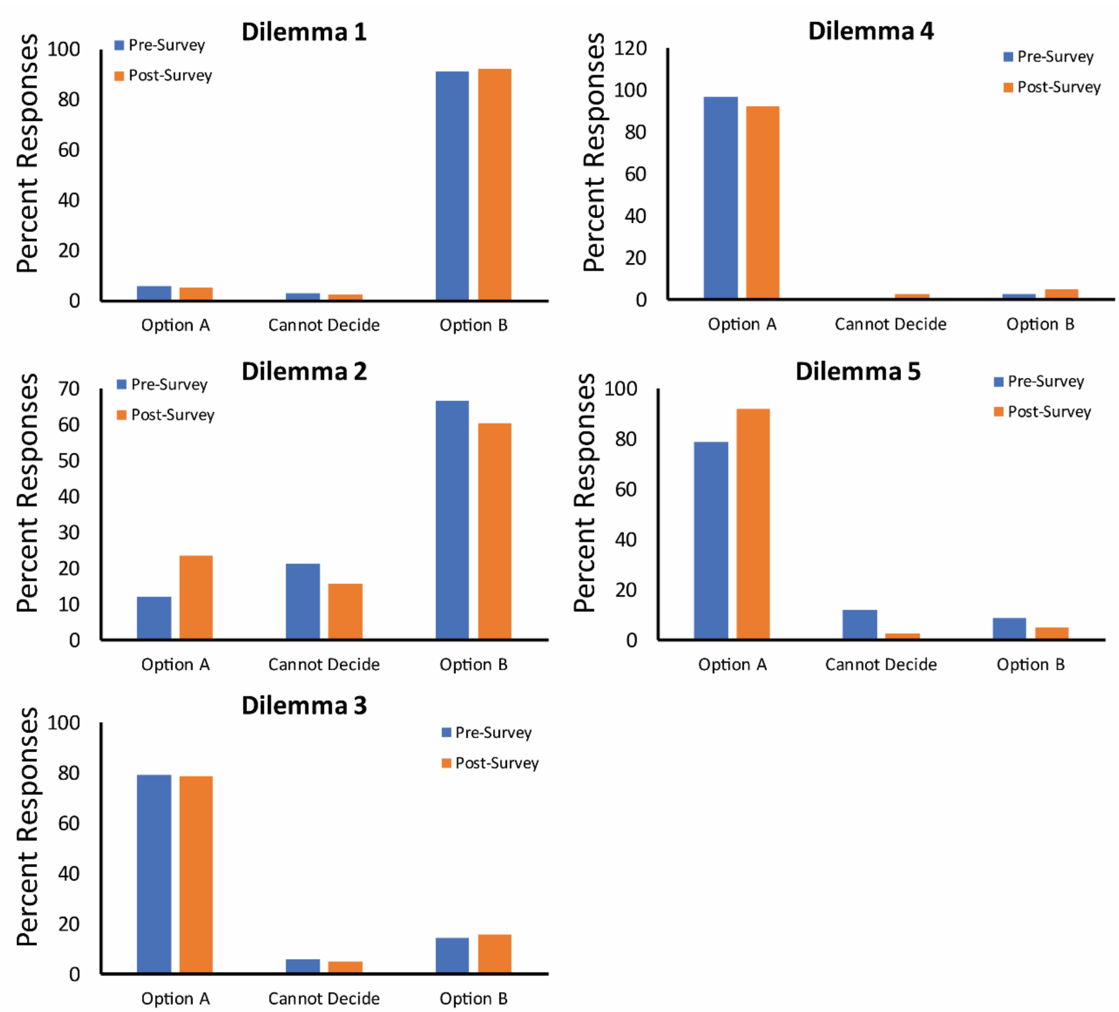

Figure 2. Summary of student responses to each dilemma in the EPSRI instrument before the learning module (pre-survey, blue) and after the learning module (post-survey, orange).

In looking at the follow-up question breakdown regarding the factors motivating the students' choice for each dilemma, we observed substantial changes in the student response for at least three out of eleven follow-up questions for all five dilemmas. For the sake of brevity, we will only include the data for the student responses for dilemma 5 which showed the largest differences in student responses between pre- and post-surveys (**Figure 3**). We found the greatest net change in level of importance for question 1 (which was related to the potential loss of production) and question 9 (which was related to additional company resources needed to replace the additive). For both questions, we observed the responses for ‘great (1)’ and ‘much (2)’ decreasing while the responses for ‘some (3)’ and ‘little (1)’ increasing. These findings suggests that after the module, the students’ placed a lesser emphasis on product production and company resources implying a greater emphasis on employee safety. This translates to a potential change in the students’ stage of moral development which is potentially a result of the learning modules. We observed similar trends in dilemma 1/question 5, dilemma 2/question 8, dilemma 3/question 8, and dilemma 4/question 9 where the motivation for the students’ response put a greater emphasis on the health, well-being, and safety of the employees and surrounding community at the expense of the welfare of the company and/or enhanced production and greater profits. This change in response also reflects a change in the students’ moral reasoning which could be attributed to moral development.

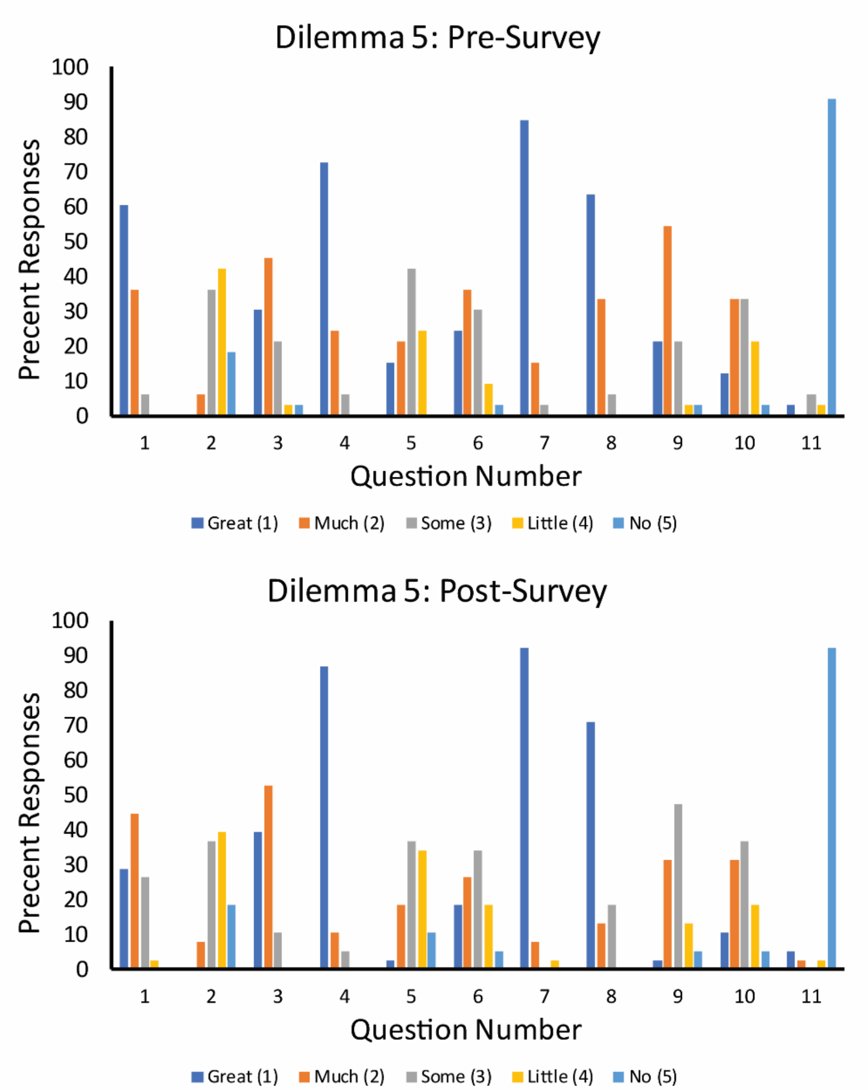

Figure 3. Summary of student responses to supplemental questions for dilemma 5 from the EPSRI instrument before the learning module (pre-survey, top) and after the learning module (post-survey, bottom).

Ultimately, the findings that the motivating factors for the students' response changed, even though many of their responses to the dilemmas did not, indicates that while they may not have changed their ultimate moral reasoning, they did change the factors that lead to their decision. This is in line with the model as Kohlberg's stages do not track specific values or outcomes, but the level of one's ability to reason about them. These results support the use and potential of the module as a method to instructor students on complex concepts related to ethics and ethical decision making.

Conclusions and Future Work

This work summarizes the development and use of a learning module for teaching chemical engineering students about ethics and moral reasoning. The centerpiece of the module is the use of the previously developed EPSRI [6] as an assessment tool in the form of pre- and post-surveys to see if the learning module changed students' response. Results from these surveys found changes in students' responses to two of out five dilemmas and several changes in the follow-up questions accompanying each dilemma related to Kohlberg's stages of moral development. A strength of the module is the inclusion of faculty from both engineering and philosophy departments as they were able to provide insight on both the technical (process safety) and ethical (moral reasoning) aspects of the module. We anticipate three possible related objections. First, that moral development requires long term work and so cannot be achieved in two class periods. Second, that our positive data may instead result from priming effects rather than actual moral development given the short time between the lesson and evaluation. Third, data from one semester may show plausibility, but long-term data is required to make the case. Future work then includes further use and development of the module to validate its impact as a method to both (***1***) teach students about ethics and moral reasoning and (***2***) assess students' understanding and mastery of these concepts. While this learning module was developed around the theme of process safety, it could be applied to other important aspects related to chemical engineering. The only challenge associated with that would be the development of a different instrument to function as a pre- and post-survey for student assessment.

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