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# First-Year Undergraduate Electrical and Computer Engineering Students Ethical Understanding Performance During an Introduction to the Discipline Course

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## Introduction

The problem of how to best teach ethics to engineers has remained a persistent issue in the discipline for many decades. As early as the 1940s, engineering professionals articulated a focus on public safety, health, and welfare, now a core tenant in the code of ethics for the Institute for Electrical and Electronics Engineers (IEEE) and National Society of Professional Engineers (NSPE). At this time, the Accreditation Board for Engineering and Technology (ABET) solidified these values when it adopted criteria requiring that ethical responsibility be included in curricula of accredited institutions [1]. As a result, college textbook authors began to include information about professional and ethical responsibility in their publications helping to further embed ethics in engineering curricula [2]. Over time, these trends have increased scholarly interest in the teaching of ethics in engineering education

Though there are two different goals for teaching engineering ethics—on the one hand cognitive understanding, and on the other hand social and moral understanding and behavior—the instructional methods used to accomplish both appear to be similar. To wit, they have often both involved active learning (specifically use of ethical dilemmas), case studies, and problem-based learning [1]. A few examples of ethics instruction identified by Walling [2] include:

- Berne and Schummer's use of discussion prompts to engage students in a discussion of the ethical implications of nanotechnologies featured in selected science fiction publication [3].
- McQueeney's use of real-world business dilemmas to prompt students to write their own personal responses, writing which then serves to prompt class discussion [4].
- Johnston's of ethical dilemmas for students to analyze in both writing and an oral presentation. In addition, students were asked to log or journal their developing ethical thoughts and concerns as they reflected upon the dilemma [5].
- Brummel *et al*' s use role-play scenarios to teach students how to conduct responsible research [6].

There is much less research focused on the use of active, problem-based learning for engineering ethics instruction. We do have sufficient information to know that active learning is generally useful in STEM fields. A meta-analysis of 225 studies by Freeman *et al.* compares student learning outcomes in lectures versus active learning in undergraduate STEM courses [7]. The researchers found that when instructors used active learning strategies, student exam scores increased significantly and student failure rates decreased significantly when compared to instructors who used lecture methods alone. Such instruction is useful in engineering specifically.

The knowledge gap in engineering education is a lack of sufficient information to show that active, problem-based learning is **more** effective for teaching ethical reasoning and decision making in college-level engineering courses than traditional lecture styles or other active learning styles. Problem-based learning is an "instructional (and curricular) learner-centered approach that empowers learners to conduct research, integrate theory and practice, and apply knowledge and skills to develop solutions to a defined problem" [8]. The PBL approach helps students determine their own learning needs and the strategies they need for learning [9]. This contrasts with traditional approaches to teaching that only introduce problems after students have acquired the relevant content knowledge and skills. Evidence from training in the medical fields suggests that PBL works well in particular contexts, especially for workplace learning with a focus on skills and long-term retention [10]. Therefore, the research question that guides this work is: *Is problem-based learning (PBL) a more effective pedagogy than a lecture-style approach (with active learning elements) to teach ethical reasoning to freshman electrical and computer engineering (ECE) students during their primary introduction to the discipline?*

To answer this research question, an introductory freshman course on the discipline of electrical and computer engineering was redesigned with an emphasis on ethical reasoning for the profession. This course was offered regularly over 3 years using both PBL and lecture-style (with active learning elements) variants with students completing 3 major assignments with ethical and technical elements. To compare the ethical achievement of both groups (PBL and lecture) student submissions were evaluated for ethical reasoning using an engineering ethics assessment rubric. The following sections outline the course redesign, student assignments, the evaluation approach, and ethical achievement results.

## Summary of ECE 121 (Introduction to Electrical and Computer Engineering)

At the University of Alabama, one-credit courses in the College of Engineering introduce first-year students to their specific disciplines (e.g., mechanical, aerospace, chemical, electrical/computer, computer science). These courses focus on basic discipline-specific concepts, along with assignments that raise student awareness of other key skills important for ABET course requirements including design, ethics, computer simulations, and life-long learning. Each department has developed its own version of this course, numbered 121, to expose students to their major discipline earlier in their program of study. The 121-course offered by the Department of Electrical and Computer Engineering (ECE 121) was selected for redesign, instead of developing a new course, because the course was already part of the department core-curriculum (preventing administrative barriers necessary for introducing a new course from impacting the project). The limitations of this decision are that the course time is limited as a 1-credit hour class and the existing ABET requirements for the course must be maintained (preventing a complete focus only on ethics in engineering). It is also important to note that this course is offered as an accelerated 5-week "mini-mester" class. This means it is delivered with 3, 50 minutes lectures per week instead of the typical 1 lecture per for a 15-week semester.

Our redesign of ECE 121 has centered ethics as a core feature of the engineering profession. The course introduces the codes of ethics from engineering societies (e.g., Institute for Electrical and Electronics Engineers (IEEE) [11], National Society of Professional Engineers (NSPE) [12]) as guides to inform the "why" behind the engineering design process rather than starting with the "how." The course is delivered as three modules with each module focused on a different set of technical topics that ethics are applied to: 1) circuits & safety, 2) materials for electronics, and 3) digital data & sensors. These specific topics were selected to continue the alignment with the power, electronic materials, and embedded systems research thrusts of the department faculty.

Each module has 5 (50 minute) lecture periods. The first 4 are focused on technical and ethical elements in these domains and the final lecture is used to facilitate small group work to solve an end-of-module problem/case study. After each lecture, students complete a graded assignment (due before the next lecture) based on the covered material. These assignments were structured to provide integrated practice of both technical and ethical reasoning skills required to complete the end-of-module problem/case study.

The PBL and lecture style courses both used the same assignments, course content, final modules, and were taught by the same instructor (the PI). This approach aimed to minimize confounding variables when comparing groups' ethical reasoning changes based on the course delivery style. To differentiate styles, the PBL variant introduced students to the final module problem during that module's first lecture. As part of this introduction students completed activities to brainstorm what skills they thought they would need to solve that problem. This approach informed the next set of lectures to develop those skills. Students were also required to complete assignments prior to attending lectures and then those assignments were discussed in class. This approach intended to empower students to explore and learn topics to approach the final problem before lectures rather than waiting for lecture content. Due to the accelerated nature of the 5-week course this scaffolding was used over a complete open-ended approach that could be implemented with a longer course. We refer to this scaffolded approach as "PBL-lite" because it aims to capture the elements of early exploration and brainstorming of PBL.

Students in the lecture style of the course completed the same assignments (but after receiving a lecture on the content) and were not introduced to the module's final problem until the last lecture of that module (with no participation in the process to think about what skills are needed for the problem). The intent of this study design was to isolate the PBL element of introducing students to a problem prior to learning the skills to approach it and comparing if this alone increases performance (with performance here referring to ethical reasoning).

**End-of-Module Problems**

At the end of each module, students completed a culminating case study/problem that was related to the entire set of technical and ethical topics covered in the module. These problems are summarized below:

> **Module 1 Problem:** Students imagine themselves as an electrical engineer contributing to the design and installation of electrical machinery for a client of their employer. This electric machine is likely to be bumped and contacted by workers at the site after its installation. As a result, an engineering review is required to understand the risks. For this problem, students are provided electric circuits to simulate and evaluate the potential current that could flow through the human body if contacted and details about the education and training of the senior engineer who designed them. In their imagined role as a junior engineer on the team they are asked to review the results, place them into the context of human safety, and provide a recommendation regarding the safety of workers around the machine.
>
> **Module 2 Problem:** Students imagine themselves as a computer engineer working for a major tech company contributing to the design of the electronics in a smart watch for health monitoring. The leadership team of the company has asked for a summary of the product

lifecycle (from mineral extraction to end-of-life disposal). In their imaged role as the computer engineer on the team, they are asked to review electronic components in the design, their relationship to conflict minerals, methods of disposal of product after its useful life, identify government regulations that impact the design, identify possible harms at each stage of the products life, and make recommendations to reduce possible harms.

**Module 3 Problem:** Students imagine themselves as a computer engineer on a research team at a university designing technologies to support athletes. As part of this team, they are asked to propose a technology to support an athlete monitoring need, prepare a pitch to outline solutions, identify the groups impacted by this technology (harms and benefits), identify privacy concerns related to personal and health data, and make recommendations to reduce possible harms if solution is implemented.

Student submissions for each module were collected using Blackboard Ultra, the course Learning Management System (LMS). These submissions were a mix of multiple-choice questions (e.g. What IEEE code of ethic is most relevant to this situation? If more than one IEEE code of ethic is relevant, what is the second most relevant to this situation?) and short-answer questions (e.g. Reviewing the entire situation, summarize the information from the case study that was most important during your evaluation of the ethical problems). Each module had questions for students to identify risks, harms, stakeholders, and potential actions to take to solve the posed problem.

After the course, student submissions were exported (as .csv files) from Blackboard for further processing and organization prior to their evaluation. Submissions were imported into MATLAB and questions relevant to the ethical aspects of the problems were used to create an individual report for each submission that organized the responses to align with the evaluation rubric (described in the following section). During this process, student names and identifying information were removed from the individual report (with each submission being assigned a unique numerical identifier). Each individual report was saved as a PDF and printed for evaluation by the study team.

**Ethical Evaluation of Student Submissions**

Student submissions were evaluated using the Pittsburgh-Mines (PM) Engineering Ethics rubric [13]. This rubric was developed to create a framework for educators to assess students' level of ethical achievement and understanding. It assesses 5 attributes: recognition of the dilemma; information; analysis complexity and depth; perspectives; and resolution. Each attribute has five levels of achievement from Level 1 (lowest) to Level 5 (highest). The necessary aspects for each level are noted in the sample rubric shown in Fig. 1. This rubric was previously validated to ensure that trained raters could achieve consistent results, with no significant differences reported [13]. These results support that this is a valid and reliable tool for assessing students' abilities to identify and resolve practical ethical dilemmas and is well suited for our deliverables.

All student samples were scored using the PM rubric by three study personnel in the summer months following the academic year in which they were collected. The study personnel who evaluated the student modules have training/expertise in electrical engineering, education, and library & information sciences. This introduces multiple complimentary backgrounds and perspectives to the evaluation of the student work. The evaluation process was blinded, that is study personnel did not know which class style each sample was collected from or from which student. This blinding was done to reduce grading bias.

**The Pittsburgh-Mines (P-M) Engineering Ethics Assessment Rubric***
**September 5, 2003**
Larry Shuman**, Mary Besterfield-Sacre, Mark Sindelar, Harvey Wolfe (U. of Pittsburgh) and Ronald Miller, Barbara Olds, Carl Mitcham (Colorado School of Mines)

| Attribute | Level 1 | Level 2 | Level 3 | Level 4 | Level 5 |
|---|---|---|---|---|---|
| Recognition of Dilemma (Relevance)* | • Doesn't see problem.<br>• At best only infers a problem | • Identifies problem(s); may infer that it is an ethical dilemma(s). | • Recognizes obvious ethical dilemma(s). | • Able to recognize less obvious ethical dilemma(s). | • Clearly identifies and frames key ethical dilemmas, or summarizes in broader context |
| Information (Argumentation) | • Uses misinformation.<br>• Uses facts incorrectly.<br>• Ignores pertinent facts. | • Lists facts without judgment or discussion.<br>• May be missing key facts.<br>• Only identifies certain actors.<br>• May recognize, but misinterpret certain facts. | • Justifies facts relevant to identified dilemmas.<br>• Notes some information is missing.<br>• Identifies most key actors. | • Recognizes some "unknown facts."<br>• Makes assumptions to address missing information.<br>• Identifies all relevant actors. | • Recognizes and justifies unknown facts in addition to known facts.<br>• Identifies primary and secondary actors.<br>• May use own expertise to add appropriate information. |
| Analysis (Complexity and Depth) | • No analysis provided.<br>• Defaults to a superior or authority without further elaboration. Takes a definitive and unambiguous position without justification.<br>• Any analysis appears to have been done without reference (explicit or implicit) to guidelines, rules or authority. | • Authoritative rule driven without justification. Position may be less definitive (e.g., "should do" vs. "must do").<br>• Minimal effort at analysis and justification.<br>• Relevant rules ignored.<br>• May miss or misinterpret key point or position.<br>• If ethical theory is cited, it is used incorrectly. | • Applies rules or standards with justification, notes possible consequences or conflicts.<br>• Correctly recognizes applicability of ethical concept(s).<br>• Recognizes that contexts of concepts must be specified.<br>• Coherent approach | • Applies rule or standard considering potential consequences or conflicts.<br>• Uses an established ethical construct appropriately.<br>• Considers aspects of competence and responsibility of key actors.<br>• May cite analogous cases.<br>Partial (incomplete) specification of contexts of concepts. | • Correctly applies ethical constructs.<br>• May offer more than one alternative resolution.<br>• Cites analogous cases with appropriate rationale.<br>• Thorough evaluation of competence and responsibility of key actors.<br>• Considers elements of risk for each alternative.<br>• Explores context of concepts. |
| Perspective (Fairness) | • No perspective; focus wanders. | • Gives one point of view. | • Some acknowledgment of multiple perspectives, but favors only one perspective. | • Considers relevant, multiple perspectives. | • Has a global view of situation<br>• Considers consequences of various perspectives.. |
| Resolution (Argumentation) | • None; not responsive to original dilemma.<br>• Proposed resolution lacks integrity; dishonest. | • Only applies or cites rules with little or no justification; may be using rules out of context.<br>• Only states possible resolution(s)<br>• Only infers consequences | • Limited ability to use facts to differentiate among alternatives.<br>• Proposed resolution is feasible<br>• Recognizes recommendation has consequences. | • Proposes several alternatives and considers consequences of each.<br>• Considers potential of risk to public and/or safety.<br>• Incomplete win-win solution suggested. | • Resolves case through clear argumentation and consideration of all primary stakeholders.<br>• Understands consequences of various actions.<br>• Proposes creative middle ground (win-win situation) solution. |

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**Figure 1:** Sample of Pittsburgh-Mines (PM) engineering ethics assessment rubric.

Prior to rating each module the personnel reviewed the instructions and questions, discussed the primary and secondary ethical problems, outlined elements for each attribute that would be required for the rubric levels, and graded 6 randomly selected student samples together. After this norming, the entire set of student samples were evaluated. The complete set of PM scores for each of the 5 attributes were recorded from each rater for all submissions. The average value for each attribute was calculated and the sum of the 5 averages calculated to represent the overall PM score to further group comparisons.

## Results

Over a period of 3-years, 308 undergraduate engineering enrolled in ECE-121 with 164 students taking the PBL style and 144 taking the lecture style. The average PM scores for each rubric attribute (and summed total) for all ECE-121 modules broken out by lecture style are given in Table 1. The total number of student samples that were evaluated were less than the total number of enrolled students because of both students dropping from the course (which is not reflected in the enrollment value and some students not submitting assignments. The set of possible scores for PM rubric range from 5 to 25 with the average scores reported here ranging from 12.72 to 13.52.

| **Table 1:** Average Pittsburgh-Mine Rubric scores for ECE 121 Modules 1-3 for students in Lecture and PBL style courses | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Module** | **Style** | **Student Samples** | **Average PM Rubric Scores** | | | | | |
| | | | **Recognition** | **Information** | **Analysis** | **Perspective** | **Resolution** | **Total** |
| **1** | **Lecture** | 133 | 2.92 | 2.41 | 2.31 | 2.99 | 2.58 | 13.22 |
| | **PBL** | 135 | 3.08 | 2.46 | 2.37 | 2.95 | 2.58 | 13.43 |
| **2** | **Lecture** | 107 | 2.40 | 2.17 | 2.51 | 3.31 | 2.33 | 12.72 |
| | **PBL** | 131 | 2.51 | 2.15 | 2.56 | 3.31 | 2.39 | 12.92 |
| **3** | **Lecture** | 116 | 2.72 | 2.43 | 2.43 | 3.52 | 2.41 | 13.51 |
| | **PBL** | 133 | 2.80 | 2.31 | 2.41 | 3.52 | 2.48 | 13.52 |

While the total scores for the PBL student samples are slightly higher for all modules (+0.21, +0.20, +0.01 for modules 1, 2, and 3, respectively) these differences are not statistically significant as assessed using unpaired samples t-tests. To visualize the range of total PM scores for all the student samples, the histograms for Modules 1 and 2 broken out by lecture style are given in 12 and the histograms for Module 3 are given in Fig. 3. Note that in each figure, the solid vertical

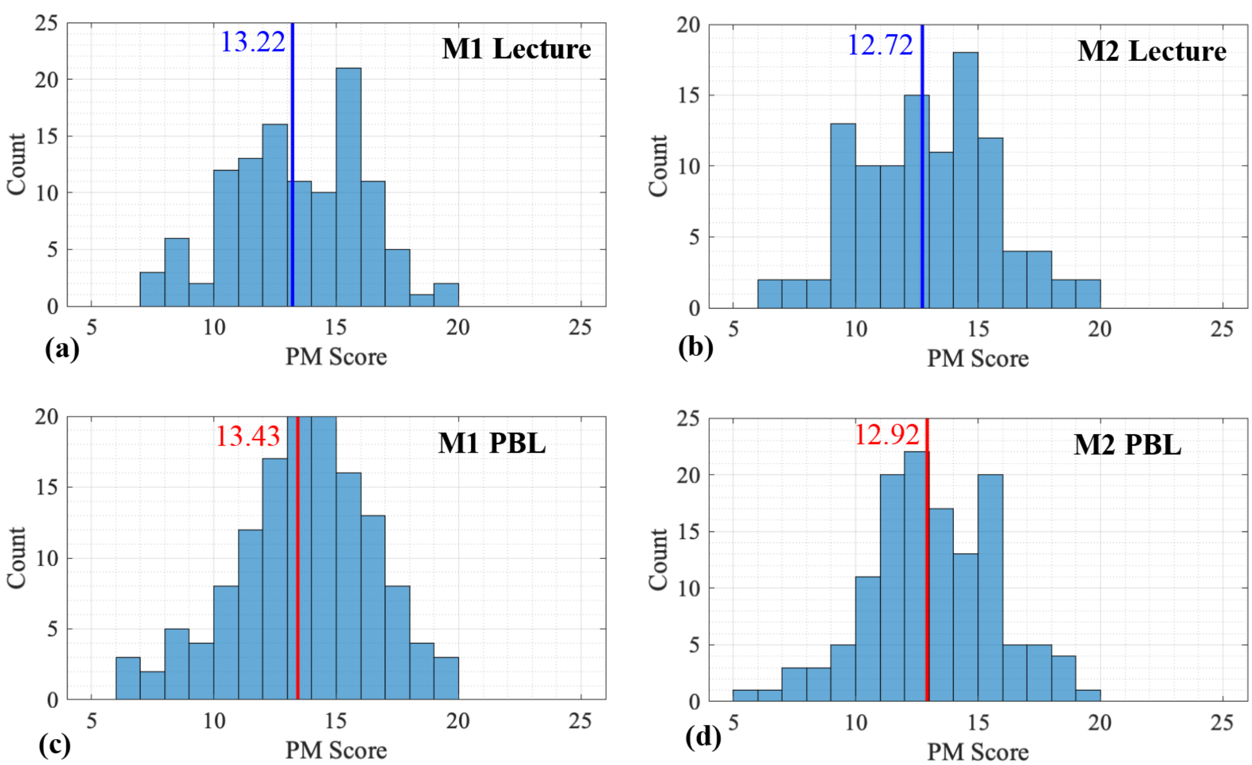


**Figure 2:** Distribution of PM scores for M1 and M2 student submissions from both PBL and Lecture style ECE 121 courses. Average group values are shown as solid vertical lines.

line represents the average value from Table 1. Student PM scores for all modules are distributed from approximately 6 to 20 which indicates achievements ranging from Level 1 to Level 4.

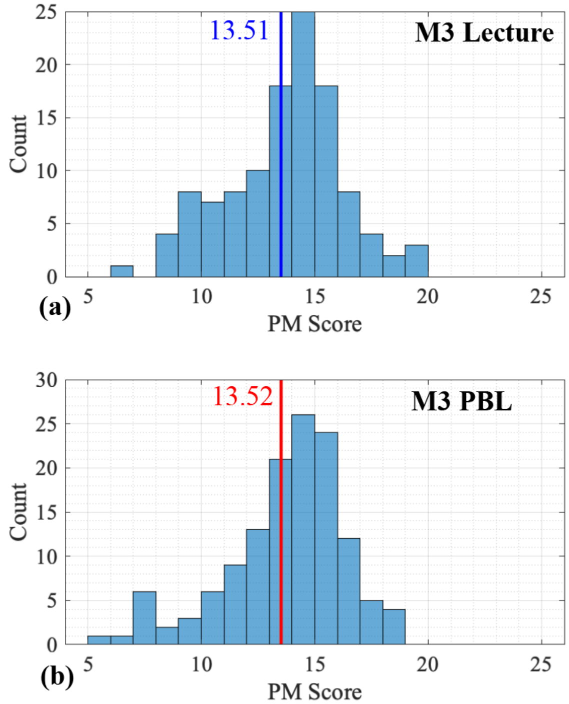


**Figure 3:** Distribution of PM scores for M3 student submissions from both PBL and Lecture style ECE 121 courses. Average group values are shown as solid vertical lines.

## Discussion

The results of this study suggest there were no differences in the ethical reasoning / achievement between freshman electrical/computer engineering students in the PBL and lecture variants of ECE 121. This suggests that the PBL elements of the course: **1)** presenting students with the motivating problem that drives further learning and investigation at the start of modules (instead of the end) and **2)** requiring students to complete readings and assignments prior to attending lectures (instead of after lectures) did not improve student achievement compared to the lecture course. These results align with preliminary data from the team that evaluated the ethical reasoning of Year 1 students [15] using the Engineering and Science Issues Test (ESIT) [16]. Using this assessment, there was not a statistically significant difference between the PBL and lecture-style scores after taking ECE 121.

We attribute the lack of differences in ethical reasoning between groups to the high-level of shared elements in each course variant. Both used active-learning elements during class activities (e.g. small group work, think-pair-shares) and the same end-of-module problems were completed by all students. The PBL elements may not have resulted in a greater level of engagement in the topics which was expected to increase performance in the end-of-module problems. Further, the potential benefits of PBL may have been limited by the accelerated nature of the course (hence PBL "lite"). With only 5-weeks for the course there was limited opportunity for students to explore ethical topics on their own and increase their understanding/mastery of these topics; which for many were their first introduction to the ethical guidelines of the profession.

Based on the PM values in Table 1, the *information* attribute was generally the lowest for all modules. Low scores for this attribute indicate that in student submissions pertinent facts for the cases/problems were ignored or misinformation was used. While the PM scores do not indicate what information was commonly ignored or what misinformation was used (which is an important topic for further follow-up investigations by the team) it does highlight that further course effort should be focused to help students improve how they search for information, how they evaluate the validity of information, and how they interpret presented information.

The highest PM values in Table 1 were generally the *perspective* attribute (2.95 to 3.52). This supports that most students in ECE 121 were able to acknowledge multiple perspectives in the case studies (but may favor only one perspective). This supports that the class activities and homework assignments that focused on identifying stakeholders who are both decision makers and impacted by decisions in engineering problems are effective (and should continue to be used in the course).

Comparing the total PM scores in Table 1, module 2 had the lowest values and indicates that students demonstrated the lowest level of achievement for this specific case. The lowest values for this case were for the *recognition of dilemma* and *information* attributes (in comparison to the other modules). Again, while the PM scores do not offer insight into reasons for these scores it is recommended that further efforts explore if the presentation of the case study may be impacting how students recognize the dilemma and connect information from the course to this case study.

While there were not observed differences in achievement between groups in this study, it is interesting to compare the performance of ECE 121 students (both PBL and lecture) to the performance of a similar student group (e.g. freshman undergraduate engineering students) on ethical case studies reported by Shuman et al. [14]. In their study, Shuman et al. reported overall average PM rubric *attribute* scores of 2.37 for freshman undergraduate engineering students completing ethical case studies. It is important to note that these students did not have any prior ethical education before completing them. For comparison, the average PM *attribute* scores in our work range from 2.54 to 2.70 (calculated dividing the total scores in Table 1 by the number of attributes). While the scores are similar, the ECE 121 students mean values are higher by +0.17 to +0.33. This may indicate that ECE 121 students increased understanding of the professional and ethical responsibilities of an engineer after taking the course than did the students studied by Shuman et al. (who did not have any ethical training). If true, this would support that while there were no differences in the lecture-style (PBL vs. lecture) that ECE 121 did improve ethical reasoning even though it was only a 5-week course.

Similar increases (+0.47) in PM scores were also reported by Shuman et al. for a group of junior/senior engineering undergraduates enrolled in an ethics related course [14]. These students completed two cases before the course and two cases after, with the increases supporting that the course did improve the ethical reasoning (and that the PM rubric was sensitive to it). This further supports that the ECE 121 students did have a gain in ethical reasoning compared to freshman engineering students who did not have any ethical training. However, it is important to note the limitations in this comparison. Different cases were used between the two studies and different raters evaluated the student work between studies. Both of which limits the direct comparisons.

What is clear from this work and the results presented by Shuman et al. [14] is that freshmen engineering students demonstrate relatively low ethical achievement. Though this is not unexpected as this group is not likely to have had previously instruction on the guiding ethics of the engineering profession. This continues to support the need for engineering ethics education for students.

**Conclusion**

Overall, this study suggests that our PBL implementation was not a more effective pedagogy than a lecture-style approach (with active learning elements) to teach ethical reasoning to freshman ECE students. This is likely attributed to the constraints for completely reshaping the course as a full semester ethical class, resulting in the choice to work with a short duration of the course (5-weeks) which limited the amount of PBL elements and total possible student activities. While no differences were reported based on teaching format, participating students had higher average ethical achievement (based on PM scores of their work) than reported scores from other engineering students. This could indicate that both courses (which used active learning elements) were successful at improving students ethical reasoning skills. More broadly, this supports that introducing an ethics focus into introductory courses with active learning elements for freshmen is a successful approach to teaching engineering ethics to electrical and computer engineering students.

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