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Board 435: Work in Progress: Teaching Ethics Using Problem-Based Learning in a Freshman Introduction to Electrical and Computer Engineering

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Introduction

The issue of how to most effectively teach ethics in engineering education continues to be a persistent concern in the field. As early as the 1940s, engineering professionals articulated a focus on public safety, health, and welfare. The Accreditation Board for Engineering and Technology (ABET) solidified this focus when it adopted criteria requiring that ethical responsibility be included in curricula of accredited institutions [1]. As a result, college textbook authors soon began to include information about professional and ethical responsibility in their publications [2]. Over time, these trends have increased scholarly interest in the teaching of ethics in engineering education.

There is strong evidence that active learning can be beneficial to learning in science, technology, engineering, and mathematics (STEM) fields in general. A meta-analysis by Freeman *et al.* of 225 studies compares student learning outcomes in lectures versus active learning in undergraduate STEM courses [3]. The researchers found that when instructors used active learning strategies, student exam scores increased significantly and student failure rates decreased significantly when compared to students whose instructors used lecture methods alone. Such instruction is useful in engineering specifically. Prince conducted an extensive narrative synthesis examining the effect of active learning in engineering education [4] and found broad support for active, collaborative, cooperative, and problem-based learning.

Problem-based learning (PBL) 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" [5]. The PBL approach helps students determine their own learning needs and the strategies they need for learning [6]. 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 [7]. 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 and how this learning impacts students' perceptions of engineering ethics and social responsibility over time. While PBL has been integrated into both medical [8] and engineering environments [9, 10], our application of PBL in undergraduate electrical and computer engineering (ECE) ethics education is largely unexplored with only a few studies having integrated this approach [11, 12, 13]. These previous studies do provide strong support for PBL in teaching undergraduate engineers; the novelty of our approach is the focus on electrical and computer engineers. This motivates our research question: *Is PBL a more effective pedagogy (than lectures) to teach ethical reasoning in support of social responsibility to freshman ECE students during their primary introduction to the discipline?*

To answer this research question, the introductory course for electrical and computer engineering (ECE 121) at the University of Alabama (UA) has been redesigned to center ethics in the profession. With this redesign, the course is offered in both PBL and traditional lecture style. In the following sections, we outline this project as a work-in-progress that includes: course redesign, evaluation of student data on ethical reasoning, and assessments of engineering professional responsibility collected in year 1 of the project.

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

At UA, 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 earlier to their major discipline.

ECE 121 was formatted as a traditional lecture-style course prior to our redesign. In the original version of the course, students attended lectures prepared by the course instructor, completed problem-sets related to the lectures, and were assessed on their understanding using assignments and in-class quizzes. The lectures broadly focused on power, digital logic, and electronic materials (which aligned with the three major research thrusts of the ECE faculty at UA). There was a brief ethics component in this version of ECE 121 offered as a stand-alone unit, where students were typically given a short reading that describes various ethical scenarios (such as fatalities from faulty airbags and autonomous vehicles) then asked to answer a series of questions about it. As a one-credit course, ECE 121 has 15-hours of instruction over the semester delivered at an accelerated pace (3-hours per week of lectures) over a 5-week period (instead of the regular 16-weeks) referred to as a "mini-mester."

By comparison, our redesign of ECE 121 centered ethics as a core-feature of the profession and theme that organizes the course. Introducing the codes of ethics from engineering societies (e.g., Institute for Electrical and Electronics Engineers (IEEE) [14], National Society of Professional Engineers (NSPE) [15]) as the guiding feature for ECE and the engineering design process helped inform the “why” behind the design process rather than starting with the “how.” After this framing of ethics as the core-feature of the profession, the course was delivered as three modules. Each module focused on a different set of technical topics, which were: 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 digital logic research thrusts of the department faculty. Each module had 5 lecture periods with the first 4 focused on technical and ethical elements in these domains and the final lecture used as a work period for small group work to solve an end-of-module problem.

The PBL and lecture style courses both used the same assignments, course content, final modules, and was delivered by the same instructor. 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. From 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. To further differentiate the PBL variant from the lecture style, students completed assignments prior to attending lectures and then those assignments were discussed in class. 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).

For the course module on circuits and safety, the final problem for the students was given to them to place them into the role of an electrical/computer engineer working in industry:

- "You and another team member are helping your supervisor design a new electrical machine for your largest client, who has purchased more than $10 million in equipment from your employer over that past 3 years (with future contracts expected to be worth $15 million). This machine is to be installed in your client's factory and is likely to be bumped and contacted by workers during its operation. As a result of this contact, the machine could transfer electrical current through workers. Because of the danger that electrical currents can pose to all persons, an engineering review of these currents is required. As a part of your responsibilities, you need to compile the detailed engineering documents and design calculations. You have been given an LTSpice electrical schematic of the electric machine to evaluate the contact currents. This schematic was designed by a senior electrical engineer and includes the electric machine as well as an electrical representation of a human body. However, no documentation about the electrical schematic was given so you need to prepare a supporting memo that provides a description of the simulation, numerical results, and the conclusion for your supervisor (prior to sharing with the client)."

Completing this problem required students to review an electrical schematic, identify an appropriate electrical circuit model for the human body, simulate an electrical circuit using a software tool, review simulation data on electrical currents, evaluate simulation data against acceptable safety standards, identify persons impacted by this situation, and justify the IEEE code of ethics most relevant. Prior to this course module students participated in lectures and activities focused on electrical current, electrical resistance, and modeling using circuits.

Problems in the same style were used for the other two course modules. The final problem for the materials for electronics module required students to explore the material extraction and end-of-life phases of consumer electronics to identify harms of each, the government regulations related to them, the IEEE code of ethics most relevant, and to generate recommendations to reduce harm. The final problem for the digital data & sensors module required students to design a wearable technology to support/monitor athletes, identify sensor technologies, identify concerns related to privacy and security, identify persons impacted, and justify the IEEE code of ethics most relevant. Common to all final projects was identifying the persons harmed in these situations and developing recommendations to reduce that harm.

The redesigns of ECE 121 were delivered in the Fall 2021 and Spring 2022 semesters. Both lecture and PBL variants were implemented in Fall 2021 and only the PBL variant in Spring 2022. In total, 76 students were enrolled in the lecture variant and 73 in the PBL variant.

Assessment of Ethical Reasoning

To evaluate students' ethical reasoning, both lecture and PBL ECE 121 students completed the Engineering and Science Issues Test (ESIT) immediately prior to their participation in ECE 121 and after completing all course activities. The ESIT tool was designed to assess how participants would make decisions about professional conduct in science and engineering [16, 17]. This tool presents six cases in story format of ethical dilemmas a scientist or engineer may face in professional practice, followed by a set of questions representing different issues that might influence a decision in that case. For each one, respondents evaluate the importance of each of the various issues for their decision-making process using ratings of importance. After rating the importance, respondents rank them in order of importance. Scores are computed with a formula that combines both the ratings and the rankings of the issues. Each case has 12 questions, with a total of 72 questions for the complete tool, requiring approximately 40-60 minutes to complete. The computed score represents an assessment of ethical reasoning, with higher scores indicating higher levels of moral judgment.

To compare ethical reasoning beyond the students in ECE 121, a control group of students enrolled in 121 introductory courses in other areas of engineering were recruited and completed the ESIT test. These students completed the ESIT only once, to provide a reference measure of their ethical reasoning (but not changes in ethical reasoning from participation in any courses).

The post-course ESIT scores of the ECE 121 lecture (LB) students, ECE 121 PBL students, and control group students are given in Table 1. Based on enrollment, the LB and PBL ECE 121 students had response rates of 79% and 72%, respectively. Based on the enrollment of students in the control group 121 courses, the recruitment materials were shared with approximately 1233 students, translating to approximately 18% response rate.

Table 1: Comparison of ECE 121 lecture, ECE 121 PBL, and control group ESIT N2 scores

	ECE 121 LB post course (N=55)	**ECE 121 PBL post course (N=53)**	**Control Group (N=217)**	**F**	***p***
ESIT N2 Score	1.89	2.08	1.83	.53	No difference

Repeated measures comparisons of the pre- and post-course ESIT scores indicated that ECE 121 students' scores were statistically significantly higher after the course than before the course (F (1,102) = 7.87, p = .006), but there was not an effect of course format, nor an interaction of course format with time. Thus, students in both the LB and PBL course formats showed similar, significant increases in scores for moral judgment from pre- to post-course assessments. An additional analysis of variance (ANOVA) comparing post-course ESIT scores across all three groups revealed no statistically significant differences in ESIT N2 scores among the three groups, although the PBL group did post the highest mean score and the control group had the lowest.

Assessment of Reasoning and Attitudes Toward Social Responsibility

To further assess students' attitudes towards social responsibility, all students completed the Engineering Professional Responsibility Assessment (EPRA) tool. The EPRA tool was developed to help educators assess curricular interventions aimed at changing students' views of social responsibility [18]. This tool was selected because of its alignment with social responsibility and engineering ethics which requires engineers to: "be aware that others are in need, recognize they have the ability to help, feel a requirement to help others, recognize that the engineering profession has the ability to help, recognize the importance of social aspects in the engineering process, and understand the costs and benefits associated with engaging in ethical actions [19]."

This measure includes 50 items within 8 subscales or *dimensions* that provide evidence of students' professional responsibility attitudes including:

1. **Awareness**: How aware students are of societal problems,
2. **Ability**: Recognition that one has the ability to help others,
3. **Connectedness**: Sense of moral obligation toward helping others,
4. **Base Skills**: Importance individual places on math, science, management, and technical skills for professional engineers,
5. **Professional Ability**: Recognition of the role of engineers in helping to solve societal problems,
6. **Analyze**: Recognition of the importance of including societal standards in the engineering process,
7. **Professional Connectedness**: Obligation engineering has towards solving problems in society,
8. **Cost Benefit**: Cost of engaging in service work in engineering.

Respondents were asked to rate their level of agreement with the EPRA items using the following 7-point scale: 1=Strongly Disagree, 2=Disagree, 3=Slightly Disagree, 4=Neutral, 5=Slightly Agree, 6=Agree, and 7=Strongly Agree. Negatively worded items were coded in reverse, such that higher scores always indicate stronger leanings toward a sense of social responsibility. For each of the eight dimensions, a mean of the item ratings was calculated to produce a dimension score for all survey respondents. The group means for pre- and post- ECE 121 LB and PBL students and the control group students are presented in Table 2.

Table 2: Comparison of LB and PBL (pre and post) and Control Group scores for each EPRA dimension

	Group Means					**Repeated measures ANOVA F values Pre-post by PBL & LB**			**Post ANOVA F values**
EPRA Dimension	**LB pre (N=76)**	**LB post (N=58)**	**PBL pre (N=62)**	**PBL post (N=54)**	**Control Group (N=251)**	**Group effect PBL vs. LB**	**Time effect Pre vs. Post**	**Interaction Time x Group**	**Post LB vs. Post PBL vs. Control**
Awareness	5.32	5.14	5.46	5.18	5.25	.93	11.81**	.08	.82
Ability	5.60	5.54	5.28	5.20	5.47	4.00*	.24	.46	2.23
Connectedness	5.23	5.26	4.88	4.77	5.17	6.25*	.03	.00	3.71*
Base Skills	5.93	5.79	5.83	5.70	5.73	.25	1.14	1.14	.17
Professional Ability	6.34	6.11	6.46	6.04	6.12	.16	15.99**	.38	.20
Analyze	5.41	5.42	5.50	5.41	5.31	.26	.31	.02	.48
Professional Connectedness	5.00	4.99	4.70	4.73	4.85	4.52^	.03	1.11	1.27
Cost Benefit	5.15	5.06	4.83	4.70	4.96	4.05*	.37	.01	2.10

^ Significance level, p = .06, * Significance level, p < .05, ** Significance level, p < .001

To evaluate differences between ECE 121 course variants a repeated measures ANOVA was conducted using the pre/post course EPRA scores from the lecture and PBL students. The repeated measures F-values for the comparisons on each EPRA dimension are presented in Table 2.

Focusing on the time effect (i.e., pre/post differences) of all ECE 121 students, the *awareness* and *professional ability* EPRA dimensions had statistically significant differences. Specifically, the post-course *awareness* score for all students in ECE 121 courses (5.18) was statistically significantly lower ($F = 11.81$, $p < .01$) than pre-course score (5.40). The post-course *professional ability* score (6.11) was significantly lower ($F = 15.99$, $p < .001$) than the pre-course score (6.44). Both dimensions did not have statistically significant differences between groups. There were no statistically significant differences (for the time effect) for any other EPRA dimensions. There were statistically significant differences between the PBL and lecture groups for the *ability, connectedness*, and *cost benefit* EPRA dimensions. The LB mean scores for these dimensions were statistically significantly higher than the PBL mean scores.

An analysis of variance (ANOVA) statistical test was completed to make group comparisons across the PBL, LB, and control groups for each EPRA dimension. For this test, the post-course scores were used for both PBL and LB ECE 121 groups. The ANOVA F values for these tests are provided in the last column of Table 2.

Comparing the mean scores between the three groups, and their statistical analysis, the post-course results indicated only one group difference for an EPRA dimension (*Connectedness).* The PBL group had a lower score (4.77) on the post survey than the LB group (5.26) and the Control group (5.17). The highest mean ratings across all groups among the dimensions were for *Professional Ability*.

Discussion

The preliminary results of our project suggest the revised ECE 121 course does result in an increase in freshman electrical/computer engineers' ethical reasoning skills based on the increase in their ESIT scores. However, there was not a statistically significant difference in the ethical reasoning ESIT scores between the style of delivery (PBL vs. LB). This does not match our expectations, which were that a PBL style would lead to greater increases in ethical reasoning. Our next steps are to continue to explore if this result holds after collection of ESIT scores from additional iterations of ECE 121 in Fall 2022 (1 PBL, 1 LB) and Spring 2023 (1 LB) to increase the number of participants in the study.

On an initial comparison of the UA freshman students ESIT N2 scores (reported in Table 1 as 1.89, 2.08, 1.83) to other available data, the UA scores are lower than those reported by Borenstein et al. for other engineering students (which ranged from approximately 2.55 to 3.58) [16]. On inspection of the groups Borenstein et al. assessed, only 3.78% of the 450 students were freshmen, with almost 80% being Juniors or Seniors. This difference in education level is expected to account for these differences (with the freshmen in our study having limited exposure to formal engineering and ethics education). How the ESIT scores of our participants change over time as they continue their engineering education will be of interest for our continued study. Specifically, we will assess if scores when they are juniors/seniors are similar to those reported by Borenstein et al. (suggesting similar ethical reasoning development over time at different institutions) and if there are differences over time that emerge between the UA PBL and LB students. As the PBL and LB students are expected to take similar courses for the remainder of their electrical / computer engineering degrees at UA, differences in scores between groups could suggest that the impact of the course was more significant over time than immediately after the course.

Exploring the EPRA analysis, it is interesting that the *awareness* and *professional ability* dimensions had statistically significantly lower scores after completing ECE 121. With *awareness* expected to measure how aware students are of societal problems, the course content related to conflict minerals in electronics and the environmental/health impacts of electronic waste globally were expected to increase this dimension. The specific items that students were asked to respond to for this dimension were:

- AW1: There are *not* communities in America that need help (reverse coded)
- AW2: Community groups need our help
- AW3: There are *not* people in the community who need help (reverse coded)
- AW4: There are people who have needs which are not being met
- AW5: There are needs in the community.

On review of these, there may have been a disconnect between the items language and the cases used in the course. Many examples in the course exploring ethical issues were global in scope (e.g., harms resulting from conflict minerals extracted globally, sites of electronic waste disposal in the world). With this global emphasis, students may not be connecting those cases with American communities. Further analysis should explore which specific questions in this dimension may have most contributed to the decrease in overall *awareness* score.

Similarly, the decrease in *professional ability* score was unexpected. This dimension measures the recognition of the role of engineers in helping to solve societal problems. The course activities and projects (described previously) were expected to increase students' attitudes regarding the role that engineers contribute to solving problems and by proxy this score. The specific items students were asked to respond to for this dimension were:

- PA1: Engineers have contributed greatly to fixing problems in the world
- PA2: Engineers' skills are *not* useful in making the community a better place (reverse coded)
- PA3: Technology does *not* play an important role in solving society's problems (reverse coded)
- PA4: Engineers can have a positive impact on society.

It may be that the content on global engineering problems (e.g., electronic waste as an effect of consumer electronics and the work of electrical/computer engineers) led to students' lower agreement with these items. Again, further analysis should explore which specific questions in this dimension contributed to the decrease in score.

Another interesting result of the EPRA analysis is the statistically significant group differences (without a time effect) on the *ability, connectedness*, and *cost benefit* for the ECE 121 PBL and LB students. This suggests an overall difference in groups that was not a result of their participation in ECE 121. This could be a result of the scheduled delivery of ECE 121 in the first year of the project. The LB format was delivered as the first "mini-mester" in the Fall semester, with the PBL formats offered as the second "mini-mester" in Fall and the only "mini-mester" in the Spring. Students enrolled in the second "mini-mester" and second semester are completing the course later in their semesters which could impact their attitudes and responses. To evaluate this effect, future years will rotate how the course variants are delivered.

Future Work

Our study is still a work in progress, having completed data collection and analysis of the ESIT and EPRA from ECE 121 students across one year (Fall 2021, Spring 2022). Our project team will continue to collect and evaluate ESIT and EPRA scores for 2 further years from freshman students and track this first cohort of students over that same period. This further data will contribute to the final analysis to answer our overall research question: *Is PBL a more effective pedagogy (than LB) to teach ethical reasoning in support of social responsibility to freshman ECE students during their primary introduction to the discipline?*

Future analyses by the study team will also evaluate student submissions for the end-of-module projects for all students. Student submissions will be evaluated using the Pittsburgh-Mines (PM) Engineering Ethics rubric [20]. This rubric assesses 5 attributes: the recognition of the dilemma, the information, the analysis complexity and depth, the perspectives, and the resolution. This rubric was developed specifically to create a framework for educators to assess students' level of ethical achievement. It is expected to help further identify if there are differences in the PBL and LB ECE 121 students' ethical reasoning. Currently, our preliminary analysis has used the ESIT to test their ethical reasoning in situations beyond the course and the EPRA evaluates their attitudes to social responsibility. But our analysis has a current gap in that we have not yet assessed differences in student work displaying their ethical reasoning on the problems of the course. The use of the PM evaluations will address this gap and evaluate ethical achievement on the specific projects the courses were designed to prepare them for.

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