Board 19: Work in Progress: Integrating Ethics Education across the Biomedical Engineering Curriculum Increases Student Awareness of Frameworks and Broader Applications to Practice

Joshua Robert Chan
Dr. Elizabeth Kathleen Bucholz, Duke University

Dr. Bucholz is an Assistant Professor of the Practice for the Department of Biomedical Engineering at Duke University and has served as the Associate Director of Undergraduate Studies for the Department of Biomedical Engineering in the Pratt School of Eng

Prof. Cameron Michael Kim, Duke University

Cameron Kim is an Assistant Professor of the Practice in the Department of Biomedical Engineering at Duke University and serves as the Associate Director for Undergraduate Education. He is researching the role of ethics-guided design frameworks in the classroom for emergent biotechnologies, including gene and cell-based therapies. His education development in molecular engineering and biotechnology results from 10 years in developing protein and RNA-based control systems for mammalian synthetic biology applications. He also serves as the faculty advisor for the Duke International Genetically Engineered Machine undergraduate research group.

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Abstract

The intersection of human health and designing novel technologies that improve medical outcomes requires personal and professional introspection on the ethical dilemmas that clinicians and engineers will face in their careers. Given the diverse field of biomedical engineering, from imaging modalities to implantable devices to emergent biotechnologies, no singular approach to ethics training will prepare our students to assess their professional obligation to the ethical, social, and legal implications of their future work. Many engineering programs provide students with early modules in engineering ethics during first-year gateway courses before reaching technical proficiency in biomedical engineering. Another strategy to incorporate ethics into the curriculum focuses on senior capstone courses with an emphasis on designing for clients and diverse stakeholders, but this approach lacks the appropriate scaffolding of ethical principles applied to engineering problems that mirrors scaffolded technical content. Accepting the broad nature of a biomedical engineering degree, we aim to engage undergraduate students in gaining proficiency and efficacy in incorporating ethical inquiry into technical knowledge that improves student engagement with course content and allows critical reflection on technical challenges for their future careers. We believe that an iterative "ethics everywhere" approach to engineering education supports students in their development and scaffolds important ethical principles in identifying ethical dilemmas and will provide value in their prospective careers.

In the Biomedical Engineering undergraduate curriculum at Duke University, we have integrated topic-specific ethics modules across all levels- beginning their freshmen year with an introductory design course, continuing through three sophomore (200-level) courses, three junior (300-level) courses, and all senior design (400-level) courses. The selected courses cover breadth in the biomedical engineering field, including biomaterials, medical instrumentation, biological modeling, imaging, and biotechnology. Topics of ethical inquiry include foundational bioethics frameworks in autonomy, justice, and beneficence; virtue ethics; ethical sourcing of materials; risk analyses of medical technologies; and fairness in healthcare costs. We have developed reflection assignments on student perception of ethics in biomedical engineering that reflect increased self-efficacy and comfort with ethical inquiry. Assessments on stakeholders and perceived risk during senior design courses indicate growth in applying case studies from previous biomedical technologies to identify potential ethical dilemmas in developing and deploying a new technology. Future work will measure student self-efficacy across the BME curriculum and post-graduation in longitudinal studies on preparation for ethical decision making as professional engineers.

Introduction

On October 16th, 2015, The Wall Street Journal [1] published an article titled *"Hot Startup Theranos Has Struggled With Its Blood-Test Technology,"* detailing complaints of Theranos employees and their concerns over the accuracy of their novel diagnostic device. This was the catalyst for the downfall of Theranos, one of our generation's infamous medical device scandals. It also highlighted the necessity of ethics within higher education, specifically in the biomedical engineering fields.

The Accreditation Board for Engineering and Technology, Inc., or ABET, defines seven expected student outcomes essential for creating an accredited program. Under Criterion 3, the fourth of these pillars acknowledges the need for "an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts." [2] An integral part of this criterion is ethics. Ethics is the study of morality and the principles that govern a person's behavior, actions, conduct, etc. Ethics studies how these moral principles form and the rational justifications of our judgments. Morality concerns the beliefs and norms about right and wrong human conduct that are widely shared and form a stable societal compact [3]. While the standards placed by ABET can be applied to general engineering, recognizing the specific need for attention in bioethical dilemmas is critical in creating a biomedical engineering curriculum that emphasizes risks and harms in unintended consequences and virtuous character development when designing novel technologies.

Advances in gene editing, such as "CRISPR babies," have brought forth new ethical dilemmas. Brain-computer interfacing companies, such as Neuralink, force us to consider what we believe to be "unnatural." Integrating these questions into a traditional curriculum can be challenging, and measuring its success can be even more difficult. A study published from 1997 - 2001 by Robert E. McGinn [4] found a disparity between students' desired ethics training and the training they received. Further investigations by Diana Bairaktarova and Anna Woodcock [5] acknowledged these gaps and developed a model that helped measure engineers' ethical awareness and predict subsequent behavior. Twenty years after McGinn's study [4], ethical dilemmas continue to exist in all subject areas, and improvement in ethical engineering education is still needed. Building off this research, we have created an "Ethics Everywhere" approach that aims to fill the gaps by integrating ethics education directly into the technical content of the student curriculum.

Research Questions

This work-in-progress aims to answer three research questions:

- RQ1: What is the status of biomedical engineering students' ethical reasoning, and how has the state of students' fundamental ethical knowledge changed over the last twenty years? To what degree have they been exposed to these principles in the context of biomedical engineering?
- RQ2: What topics or ethical foundations does the biomedical engineering community (e.g., students, faculty, industry) consider valuable? Which topics are already being taught to students, and what should be integrated into the curriculum?
- RQ3: How effective is the "ethics everywhere" approach in integrating ethical reasoning into the current biomedical engineering curriculum? Does incorporating ethical learning broadly into required engineering content-based courses improve ethical reasoning and long-term character development?

Planned Methodology and Future Results

Defining the current state of students' ethical knowledge: To understand the current ethical reasoning of students, three questions from a pool of eight will be posed to Duke University BME students enrolled as either freshman, sophomore, junior, or senior undergraduates. The questions will focus on current ethical topics in the biomedical field. Examples of these topic fields are medical imaging, gene therapy, and medical devices. The questions will be discussed in a one-on-one and/or interview. Recorded responses will be transcribed and scored on a Likert scale of 0-4 based on the rubric created in Shuman's study [6]. The categories are as follows:

1. Recognition of Dilemma: On the low end of the range would be misidentifying the ethical issue. Opposed to this would be stating the key dilemma of the situation.
2. Information: The low end of the spectrum would be represented by students who fail to use relevant logic or utilize misinformation. The other end of the spectrum would be students who state assumptions justified by facts or their experiences.
3. Analysis: A low score would represent students who fail to provide any analysis, whereas a high score would represent comparisons drawn to analog cases or connecting ideas and determining their differences.
4. Perspective: The base level would provide no perspective or viewpoints to the situational, whereas a high-level response would analyze the dilemma globally, including multiple stakeholders.
5. Resolution: The lowest level responses would provide no resolution or cite out-of-context rules. The ideal responses would engage the issue on multiple levels, consider risks for different parties, and present a middle-ground solution.

The problems will be derived from multiple sources. Four scenarios will be taken from Shuman's [6] original study: *Artificial Heart* and *BioVis,* written by Ferrari and Pinkus, and *Tools* and *Trees,* originally presented by Pritchard and colleagues. The remaining topics will include implantable birth control, CRISPR babies, electronic fetal monitoring, and lead aprons for X-ray imaging. An example of a case study based on the current use of lead aprons for X-ray imaging and its criterion are included in Appendix A. [7][8]

An estimated 24 students will patriciate in our focus group studies, with each academic year representing a quarter of our sample size. Our team will use a deductive approach and generate a rubric and score responses based on the above criteria. A minimum of two evaluators will score each set of responses and their values will be averaged together. Each response will be categorized by academic year and an ANOVA test will be used to evaluate the results. The analyzation of these responses will be done using qualitative coding data analysis software NVivo 12 to identify common themes and ensure constancy between different groups and graders.

After collecting data from interviews, we will compare them to Shuman's previous study [6]. This will allow us to analyze the trends in ethical reasoning from a previous study to assess if there have been any significant changes in ethical learning outcomes. We have received IRB approval (#2023-0381) and are currently collecting data for this study entitled "*Integrating ethics education across the biomedical engineering curriculum increases student awareness of frameworks and broader applications to practice.*"

Identifying desired ethical principles and understanding their inclusion in engineering education:

In-class surveys will be given to undergraduate students in multiple courses in the BME department. This exercise is modeled after McGinn's study [4].

We reframed multiple questions from McGinn's study [4] to focus on biomedical engineering scenarios and education. We will administer an initial survey and a final survey to analyze the current implementation of ethics in our curriculum based on student year. Our survey will seek to quantify the following three questions.

1. Do students believe that they will face ethical challenges in the future, and how does this belief change as students' progress in their undergraduate education? Do their future career goals affect their answer? (Underline emphasis our own as novel questions for our study)
2. Do students believe that ethics are important, and how does this belief change as students progress in their undergraduate educations? Do their future career goals affect their answer? (Underline emphasis our own as novel questions for our study)
3. Do students believe that the current curriculum and faculty properly address ethics and enforce their importance?

Survey questions addressing these topics will be quantified on a 0 - 4 scale. One such example is included in Appendix B.

We added specific questions on future career goals as many biomedical engineering students do not become practicing engineers or receive professional licenses [9]. Given recent trends in biomedical engineering career placement as favoring jobs and graduate school post-baccalaureate, we wish to analyze how ethical reasoning changes within career paths and the growing role of ethical decision-making in industry science and engineering positions.

Surveys allow students free response answers to justify their statements. We will continue to utilize NVivo 12 to identify common themes in ethical awareness in the engineering or related professions our students plan to pursue based on their responses. Utilizing this software will maintain consistency throughout the analyzation process.

To assess the results, both the quantitative and qualitative responses will be aggregated and compared to McGinn's original and follow-up studies [4]. This will allow us to assess changes in curriculum and how they have affected our student's understanding of ethical principles. Our initial and final surveys will allow us to improve the curriculum within our biomedical engineering department with a broader impact on other engineering fields and universities to adopt an "ethics everywhere" approach to curriculum development.

Future Directions

Currently, our department utilizes the "ethics everywhere" approach. Comparing our data to McGinn's and Shuman's studies allows us to draw concurrent conclusions about the effectiveness of this strategy and the development of ethical reasoning over time among our students. Future studies should seek to compare the ethical knowledge and growth of students who experience an "ethics everywhere" curriculum versus other approaches such as capstone or standalone general engineering ethics courses. We would like to continue this study over different populations, such as alumni, and compare how their expected experience and education compare to their professional career experiences.

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Appendix A: Focus Group Example Case Study

Lead aprons were commonly used to protect patients (particularly reproductive organs) from scatter during routine X-ray scans. With improvements in technology, scatter has been drastically reduced and now lead aprons can actually cause patients to be exposed to more harmful radiation as they can interfere with some of the automatic sensors that determine the mean effective X-ray energy to use and can also get in the way of the scan, ultimately resulting in some patients needing to be rescanned. Should lead aprons still be utilized in typical hospital procedures?

Included below are examples of responses that would be given 4's in each category.

1. Recognition: There are advantages and disadvantages to using lead aprons. What was employed to protect patients is now actually causing patients to be exposed to more X-ray radiation.
2. Information: Lead aprons may lead to more harmful rays due to causing the system to erroneously increase mean effective X-ray energy as well as interfere with the field of view of the scan; however, patients may feel uncomfortable without them as they have grown accustomed to having them and thinking that lead aprons are protective.
3. Analysis: This situation could be similar to the introduction of seat belts, it may improve safety, but some people refuse to utilize them when they were introduced.
4. Perspective: Doctors, Nurses, patients, and hospital administration all have different perspectives on this. Not only does having to redo a scan expose the patients to more X-rays, but it also costs more money for the same procedure.
5. Resolution: Not utilizing lead aprons may be the safest approach, but patients must be educated to prevent fear or unnecessary anxiety.

Appendix B: Survey Question Example with Scoring:

"To what extent has your undergraduate education helped prepare you to thoughtfully and effectively address possible engineering-ethical challenges you may encounter in your career?"

(0) = no impact
(1) = minor impact
(2) = somewhat prepared me
(3) = prepared me
(4) = significantly prepared me