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Uma Balaji

Isaac Macwan

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Embedding Environmental Ethics in Engineering Courses

Dr. Uma Balaji, Fairfield University

Dr. Uma Balaji received her Ph. D from University of Victoria, B.C., Canada in Electrical Engineering. She was a Canadian Common Wealth Scholar. Her research focused in novel modelling techniques to design components for wireless and satellite applications. Some of the components designed and fabricated by her include RF power amplifiers, antennas and filters. Another area of her research and teaching interest is Electromagnetic Compatibility (EMC). Prior to joining Fairfield, she is a recipient of the University Grants Award from IEEE EMC society to develop and teach a course on EMC. She is a Senior Member of the Institute of Electrical and Electronic Engineers (IEEE) and a Professional Member of ASEE. She was the Chair of the Affinity group - IEEE Women in Engineering of Long Island Section, NY in 2012 and 2013 and Vice Chair of Educational Activities Committee, LI section. Her research interests include Design of Radio Frequency and Microwave Components, Antennas, RF power Amplifiers, Electromagnetic Compatibility and Signal Integrity. She teaches the following courses: Electric Circuits, Electronic devices and Circuits, Signals and Systems, Electromagnetic Compatibility, Communication Systems and Numerical Methods in Engineering

Dr. Isaac Macwan, Fairfield University

Working in the field of Bioelectronics on molecular dynamics studies at the interface of biological macromolecules and nanoparticles and bacterial assisted nanofabrication strategies utilizing carbon based nanomaterials.

Embedding Environmental Ethics in Engineering Courses

Introduction

Engineers are required to perform under a standard of professional behavior that requires that they demonstrate highest principles of ethical conduct. To help engineering students gain this competency, many approaches are practiced, one of them is through a dedicated course on engineering ethics. This approach has the benefit that students in different majors enrolled in the course get to examine ethical issues through the broader lens of engineering discipline rather than being major specific. Even where the course may be major specific, teaching through case studies particular to that major raises awareness among students on safety, health and welfare of the public and thus elevates ethical and moral responsibility in the profession [1].

At the Fairfield University, we currently teach engineering ethics to students by integrating relevant material into several courses. Embedding ethics into several courses right from the freshman course in engineering, namely introduction to engineering, followed by selected courses and finally at the capstone course would be one of the approaches to mainstreaming ethics. This could help reiterate principles and standards related to ethics when ethical considerations are addressed concurrently for various engineering topics effectively. Introducing students during the freshman year to code of ethics from different professional societies such as ASME, NSPE and IEEE in the fundamentals in engineering course as well as in their students' clubs is actively pursued at the Fairfield University. Ethics related issues are discussed during class and through assignments in all relevant courses, bolstering students' ability for ethical behavior in their professional pursuit. Further, while taking the two-semester sequence constituting the capstone design experience covered by Senior Design courses at the school of engineering of the University, students are asked to examine ethical issues and impact related to their product design.

In this paper, we discuss two courses, one each in electrical engineering and biomedical engineering on how materials related to environmental ethics are integrated through specific assignments. There is increasing interest among engineers and policy-makers on environmental ethics in recent times. Suitable content for in-class discussion on environmental ethics was included to cultivate the attitude of responsible behavior among students. The first IEEE code of ethics [2] notes: "to uphold the highest standards of integrity, responsible behavior, and ethical conduct in professional activities". The objective in our courses was to cultivate a responsible behavior among students in safeguarding the environment and promote not only an awareness of good practices but also be an advocate as they move on to professional practice later.

Among the many ways of achieving the above objective, the IEEE code of ethics [2] further notes that the members commit "to hold paramount the safety, health, and welfare of the public, to strive to comply with ethical design and sustainable development practices, to protect the privacy of others, and to disclose promptly factors that might endanger the public or the environment." Scientific research that brings change and advancements could on some instances endanger the environment. Proliferation of electronic devices that use rechargeable batteries and

its improper disposal is one example. In a required course 'Introduction to Electric Circuits', we discuss energy, sources of energy and consumption of energy. An examination into practices related to disposal of batteries can be assigned to students to learn compliance, safety and ethical or responsible behaviors. In an elective course for Biomedical engineering titled 'Biosensors', we discuss whole-cell biosensors developed using synthetic biology for environmental policing that require careful examination before they are introduced into the environment.

These courses lend suitable venue for creating an awareness among students on the possible risk to health, safety and the environment by innovations and the need to comply with established ethical standards.

Methods

'Introduction to Electric Circuits' is one of the foundational engineering courses that introduces students to the analysis of linear electric circuits. At Fairfield University, this course is taken by students pursuing majors in Biomedical, Electrical and Mechanical engineering. Integrating elements of ethics in this course with appropriate follow-up assignment has the potential to influence students of all three majors to not only gain relevant technical knowledge but also have classroom experience on norms and standards as well as compliance issues that can impact on their practice of code of ethics.

The first chapter of the course introduces students to basic concepts including different electrical quantities their units, definitions, understanding of power and energy. The topic of energy usage and the need for conservation with growing demand is briefly discussed [3]. This was found as a suitable entry-point for a discussion on ethics related to consumption, sustainability and environment. While discussing energy sources, a mention is made of different type of batteries including those used in cell phones and automobiles. The use of different units to describe energy specification namely *Ampere-hour* and *watt-hour* are discussed. An example problem on *Ah* and *Wh* units is solved in the classroom. A problem on how long a rechargeable battery can operate while drawing a constant current from it, is also solved. This problem is useful to students when they work later on capstone projects where they may be required to identify a suitable battery for their senior design course. Simultaneously, it opens an opportunity to discuss briefly on the materials used in batteries and their potential harm to the environment [4] depending on how they are disposed.

Based on these discussions an assignment is given to students. While the points assigned to the project are only three percent of the total grade, the goal of the assignment is to encourage researching sources and reading materials relevant to appropriate disposal of different types of batteries that can harm environment. Further, students gathered information related to responsible behavior and examined how different individuals practice the same. Another goal was for students to assess people's perception and attitudes and find ways to contribute through volunteerism or find ways to create solutions that can mitigate harm to the environment.

Students are encouraged to answer selected questions as part of the assignment and prepare a document of no more than two pages with answers. They were advised to include citation to the researched articles or sources used. The questions posed for the project did not directly mention

responsible behavior in safeguarding environment but gently directed them to reflect and think about. The questions in the assignment included an image of a commonly used cellphone battery that was specified in *Ah, Wh*., along with the output voltage and charge voltage. The image indicated that the battery should not be disposed of in routine garbage disposal system.

The questions included in the assignment for students to prepare their document on, were:

1. What are the *Ampere-hour (Ah)* rating and the output voltage indicated on the label of the battery shown. Calculate the *watt hour (Wh)* from its terminal voltage and *Ah* specification and check if the labeled specification (image indicated this as well) matches the calculation.

2. Mention the chemical composition of such type of rechargeable battery for cell phones shown to you. Mention also the chemical composition of batteries used in automobiles for ignition?

3. What are your concerns about disposal of such batteries? Collect references on where and how they are disposed in your area of residence. Collect information on public policy on disposal in two different countries from a Google search.

4. Please interview five people known (could be family or friends but should not be member of your current class) to you on how they disposed such batteries? Include their response without revealing their names.

5. Do you think it is important to work toward this cause of ethical disposal of waste? Suggest ways that you may choose to work towards this cause.

The Biosensors course is an elective course in biomedical engineering major and is taken at junior or senior level. Studying environmental ethics within the context of biomedical engineering is important from the viewpoint of creating and maintaining a sustainable environment where technologies used to design and fabricate biomedical devices should not only be environmentally friendly but also such that generate products that are biocompatible and biodegradable. Bioelectronics is a subspecialty of biomedical engineering that deals directly with such design and fabrication of devices, which are used in clinical diagnostics, bioinstrumentation and patient care.

A portion of this course deals with teaching and familiarizing undergraduate biomedical engineering students to the ethical implications of using biosensors both as clinical devices and environmental surveillance tools. Students are informed of how the legal issues are different from ethical issues. In the former they have formal rules, which are specific and well documented, and violation of these rules is met with consequences in the form of punishment and sanctions. Ethical issues on the other hand are moral principles, which are typically documented through Code of Conduct by the many professional bodies, and which do not have severe punishment unless there is a parallel violation of legal issues.

In the context of biosensors, there are issues related to the environmental ethics when it comes to synthetic biology and the use of engineered prokaryotic whole-cell biosensors. It is important to realize how the biosafety of the environment is directly linked to the possibility or risk of these

genetically engineered biosensors being released in the environment [5]. Whole-cell biosensors, which are used in biomedical diagnostics and environmental monitoring, are engineered microorganisms that detect and report a target or condition of interest [6]. Such whole-cell biosensors, otherwise known as cellular biosensors, involve selection of reporter genes and their regulatory proteins, improvements in performance through microelectronic and information technologies and integration of these sensors with nano and micro integrated chips. With all the amazing solutions to the biomedical and environmental monitoring problems, it is found that there is a possibility of some of these engineered organisms to persist and spread despite the efforts to control them, affecting the normal functions of an ecosystem by transferring their altered DNA to other microbes. Unlike transgenic crops, synthetic microbes may alter in more sophisticated and fundamental ways, thereby making them more difficult to monitor and regulate.

Based on these ideas, undergraduate biomedical engineering students are assigned two articles and two chapters from the Handbook of cell biosensors by Gerald Thouand [7], to understand the ethical implications of using whole-cell biosensors for environmental monitoring and complete an assignment with questions related to the description and role of whole-cell biosensors, their implications to environment and ethical regulations to scrutinize the engineered micro-organisms before they are released into the environment.

They prepare a document that answers a series of questions in no more than two pages. They are also asked to collect information on public policy and cite sources used. The questions shared with students are –

1. Describe what whole-cell biosensors are and their applications in clinical diagnosis and environmental monitoring.

2. What is the role of synthetic biology in developing whole-cell biosensors? Describe how selectivity, limit of detection and output dynamic range are improved for such biosensors.

3. Discuss with one other classmate why biosafety is of vital importance when dealing with whole-cell biosensors for environmental monitoring and submit no more than five sentences of your discussion (without citing whom you discussed with). What are the four research risks associated with using whole-cell biosensors for environmental monitoring?

4. Do a literature survey and use appropriate online sources to list one or two strategies that are being utilized to remedy the four risks mentioned in Q3. How do you think scientists should respond to create a solution to protect the environment?

5. It is known that once the whole–cell biosensors (engineered micro-organisms) are released in the environment, they cannot be retrieved. Identify at least one regulatory body and two to three ethical regulations that are in place to scrutinize the nature and behavior of the species before they are released in the environment?

Discussion

An analysis of students experience on environmental ethics based on their response to the assignment specifically to questions 3 to 5 in the course on 'Introduction to Electric Circuits' is discussed first, followed by that in 'Biosensors'.

Environmental ethics in the course 'Introduction to Electric Circuits'

In the assignment to forty-four students attending the course on Introduction to Electric Circuits' during the Fall 2021 semester, an image of the Lithium-Ion battery was provided with the five questions. All students provided their detailed response with references including websites that they referred to, to complete their assignment.

Summary observations from first two questions including chemical composition – In addition to responding to the Q1 related to the calculations, at least 36% (16 out of 44) responded that the review made them aware of the material used, the chemical composition of different types of batteries, the environmental implication of the use of such material. Many students specifically commented on the heating potential and fire hazards during storage, transport etc.

Battery disposal locations, concerns and policy – Students described various options to dispose/recycle different types of batteries. They researched popular websites and also noted popular stores outlets in their areas which have provisions for collecting used batteries. They also described various options established by their cities including the 'Transfer stations' nearest to their homes in the tri-state area for recycling batteries. Over 50% of students had referred to one of the government sites including those of Environment Protection Agency (EPA), Department of Energy and Environmental Protection (DEEP) as well as popular websites through Google search engines on the subject.

On the policy front, almost all students researched policy options and recommendations for disposal and recycling of batteries in their states; some also compared these options with those in the neighbouring states. Two students referred to availability of 'gift card' options if you recycle batteries. On examining policy in other countries, majority of students chose Canada, EU, Germany and UK as the foreign countries for review of policies related to batteries recycling while two or more students looked at similar policies in Brazil, China, India and South Korea. One student each looked at the policies in Czech Republic, Hungary, Japan, Lithuania and Sweden. Two students commented that most of the low-income countries do not appear to have any policy or position on recycling of batteries. Some students reported that EU have stricter policy on e-waste. Some students also discussed environmental effects including the possibility of lead and Lithium entering drinking water and ground water leading to contamination as well as the potential harmful effects on plants, animals (including fish) and their habitations as well as humans.

Batteries disposal practice among friends/family – All of our students were required to randomly ask 5 friends and family members on the battery disposal practice. The table below gives an overview of the responses:

Table 1 Students reporting awareness of correct disposal of batteries based on interviews

No. of students	Number Aware of safe disposal / Number surveyed	Percent report aware of safe disposal
10	10/50	20%
14	28/70	40%
10	30/50	60%
5	20/25	80%
5	25/25	100%
Total:44	**113/220**	**51.3%**

The forty-four students together had asked five of their friends and/or family members about how they dispose of recyclable batteries. Five (out of 44) students reported that all of the five respondents that they contacted knew the correct method to discard or recycle used batteries. It was disappointing to note that 10 (out of 44) students found that only one of the five friends or family members they contacted knew the correct method of discarding or recycling used batteries. Of the total 220 respondents, 113 (51.3%) of them have been reported as disposing off batteries correctly such as using relevant bins in major outlet stores, using transfer stations, returning to major battery stores or discarding them appropriately labelled recycle bins/cans in relevant locations. While the five members identified for asking these questions were not identified systematically and the methodology was mainly devised to get a general awareness of the practice around them, the students were amazed that generally older people such as parents, grandparents in the community or families knew about the recycling need and/or generally returned used batteries to appropriate stores or transfer locations, the younger respondents including friends and peers generally discarded them in trash cans and garbage cans without registering the fact that there was an imminent harm in doing so. Some students noted in their assignments that even they themselves or their friends who were very conscientious about use of plastics and recycling them were not aware of the appropriate methodology for discarding used batteries.

Recommendations – way forward - All the students who found respondents who were not aware or are not practicing a correct way of discarding or recycling used batteries shared information on the need to, and the reason why used batteries need to be disposed of or recycled in the correct manner and what options were available as per public information from their city or state. In addition, some students felt that there has to be better public education measures for spreading awareness including the dangers of discarding in garbage can and landfills. One student recommended that he would begin a University club for the purpose and another felt that advertisements and commercials on similar lines for drugs and pharmaceuticals should be mandated for all manufacturers of batteries. Three students recommended that younger people beginning from middle and high schools need to be given training and awareness of the need to secure their environment and resources. One student even suggested that online sellers of

batteries should have a built-in mechanism for collecting used batteries from the customers. One student recommended additional incentives including ‘gift cards’ and tax-breaks for those who dispose of used batteries correctly, the same way those disposing used clothes and shoes are given benefits while filing their tax returns.

An anonymous survey was administered to one out of the two sections of students and thus forms only a sample of 18 participants from among the 44 students. Seventeen out of the 18 students responded to three questions on a five-point Likert scale from Strongly agree to Strongly disagree. None of the students responded negatively to the three questions. The response rate and the overall positive response suggests students’ commitment to the cause despite low weightage given to the assignment. The full findings are summarized below:

Table 2 Usefulness of the Environmental Ethics assignment

Issue	# Strongly Agree	# Agree	# Don’t Know / Can’t say
Better informed on how I can contribute to safeguarding environment by discarding batteries (electronic wastes) appropriately	**9 (53%)**	**7 (41%)**	**1 (6%)**
Helped me analyze challenges in people’s actions having a direct bearing on environment	**8 (47%)**	**8 (47%)**	**1 (6%)**
I can/will contribute to changing behaviors to strengthen communities for creating sustainable human society	**8 (47%)**	**7 (41%)**	**2 (12%)**

While almost all of them felt that the assignment was very good or good and the duration was just right, one respondent felt that it could have been longer and that we could have discussed different types of batteries and taught additional lessons around how batteries are further dis-assembled and essential components recycled at the recycling plants.

For Biosensors class, we are awaiting the data for Spring 2022 semester. Currently, there are six students in the course and it is anticipated that this number will increase in the future. The data collection will be based on three items from the assignment, 1. importance of biosafety and the research risks associated with the whole-cell biosensors, 2. strategies being utilized to remedy the four risks and 3. identification of a regulatory body and two to three ethical regulations that are in place to scrutinize the nature and behavior of the bioengineered species.

An anonymous survey will also be administered upon completion of the assignment on 5-point Likert scale from Strongly agree to Strongly disagree. The survey will cover questions including 1. If they are better informed to safeguard the environment against release of harmful bioengineered species, 2. If the assignment helped the students in analyzing the biosafety of environment, and 3. What is their take on contributing to the change in behavior and strengthening the communities to help create a sustainable environment.

Conclusions

A simple assignment on the analysis of harmful effects on the environment if batteries are not disposed safely in an introductory course on electric circuits has been used to educate and encourage practice of responsible behavior among students in different engineering majors.

Similarly, an assignment on the biosafety aspects of the environment related to the use of bioengineered whole-cell biosensors is described and have been assigned to the students in the Biosensors class. Survey indicated that the assignment promoted the awareness of ethical responsibility as an engineer to safeguard environment. Many students have collected information and have mostly agreed to working towards changing behaviors to strengthen communities and help create a sustainable society. The goal of the assignment which was to cultivate a responsible behavior among students in safeguarding the environment and promoting an awareness of good practices and being an advocate has been largely successful.

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