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ETHICAL ISSUES IN ELECTRONIC AND ELECTRICAL ENGINEERING

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Introduction

As is evident throughout this handbook, ethics education in engineering takes many forms. In this chapter, we focus on the discipline of electronic and electrical engineering (E&EE) with the aim to provide examples of various discipline-specific approaches for the classroom. We hope E&EE educators may be inspired to try one of the approaches or develop their own. This, and the other discipline-specific chapters (Chapters 14, 15, 17, and 18 of this handbook) showcase the importance of including options for students that engage their disciplinary interests rather than only generic 'engineering ethics' where some of the examples might not resonate with students. For instance, the examples of failures of bridges or hotels may not seem as relevant to electrical engineering students as examples drawn from consumer electronics. It is important for E&EE students to conceptualize ethics as not merely an academic exercise but something relevant to their lives and professional practices. In addition, engineering ethics is an inherently interdisciplinary field, spanning multiple engineering as well as social sciences disciplines, and including ethics in engineering curricula helps students see the value of knowledge in other disciplines.

In this chapter, after describing our positionality as authors, we then compare ethics education in electronic and electrical engineering to other engineering disciplines to highlight why we believe that ethics has not had as much prominence in E&EE as it has had in some other disciplines. Following this, we discuss the importance of ethics within E&EE education. We consider the literature on ethics specific to electronic and electrical engineering education, including discussions of professional responsibility connected to codes of ethics and E&EE courses. We provide examples, from the literature and our own work, of integrating ethical considerations into specific technical E&EE courses. We demonstrate that although there are ethics-related case studies available, relatively few relate directly to electronic and electrical engineering; those relevant for E&EE mostly cover general engineering considerations or codes of conduct rather than E&EE scenarios. We propose that instructors draw from the teaching models and ethical issues and concerns presented below; various educators and researchers have identified these concerns and used these models to integrate ethical issues within the delivery of technical content. The presented set of E&EE-related concepts and models is not exhaustive; rather, we aimed to identify broad topics and identify some specific problematic examples from E&EE culture that instructors can use to

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facilitate in-class discussions. We believe these can be integrated within the context of technical content delivery.

Positionality

We, the two authors of this chapter, are electrical engineering educators with decades of experience in academia. We have held leadership positions in the IEEE Education Society. Susan Lord is a white cisgender woman with undergraduate and graduate degrees in electrical engineering who is a full professor at a US university focusing on teaching. Her research is in engineering education. Her experiences of marginalization as a woman in E&EE have contributed to her desire to change the culture of E&EE to be more welcoming and inclusive. John Mitchell is a white cisgender man with undergraduate and graduate degrees in electronic and electrical engineering and a full professor at a research-intensive UK university. His career started with research focused on communications systems but has developed to focus mainly on engineering education, particularly curriculum design. Both have been involved in developing integrated programs where technical and transferable skills, such as ethics, are combined within the curriculum. We acknowledge that our positions of privilege have informed our approach to our work, including the writing of this chapter. Thus, our examples are drawn from the published Western literature that we know best.

Ethics in E&EE compared to other disciplines

Fleddermann (2000) stated in the opening of his paper on ethics case studies that "Rarely is electrical technology at the focus of the classic case studies used in engineering ethics courses and textbooks" (p. 284). Our research for this chapter has demonstrated that this continues to be the case two decades later. Although ethics is undoubtedly taught in electrical engineering courses, the case studies tend to be situated outside the discipline or to address professional issues where the setting is electrical and electronic engineering but the E&EE context is not central to the ethical issue at hand (e.g., whistle-blowing in semiconductor manufacturing that could be in any manufacturing process). Although research (e.g., Barry & Whitener, 2011) has suggested that electronic and electrical engineers are reasonably well prepared to handle ethical issues, this may be because ethics classes have typically considered generic, professional ethics rather than issues directly linked to the discipline (Bielefeldt et al., 2018).

We argue that it is important for students to grapple with ethical considerations (a) explicitly relevant to their discipline, (b) integrated into their technical studies, and (c) taught by engineers. To accomplish this, it is crucial to understand why electrical engineering case studies are rare. We hypothesize that while other branches of engineering produce infrastructure that is directly public-facing – civil engineering (buildings), chemical engineers (chemical plants), mechanical engineers (cars and planes) – electronic engineers especially (but also electrical engineers) build components that are within all these engineered systems or products. This degree of separation means that direct ethical considerations related to electrical and electronics engineering are less obvious than those within other engineering disciplines. Of course, this is just a perception – and one that in many areas has never been entirely true and becomes less so with computer systems and electronic control being at the heart of the modern world. This view is encompassed in the growing refrain that modern engineering and modern engineering graduates must be equipped to grapple with the ethical and social aspects of engineering and the technical aspects. To do this effectively, they must perceive ethical considerations as central to the problem-solving process of their discipline, recognizing that a 'good' solution must be ethical, sustainable, and inclusive just as much as technically feasible, manufacturable, and financially viable.

Although many of these ethical considerations will be social or professional in nature, some will be technical and can be quantified with calculations and technical arguments. The next section describes enacted and proposed approaches for bringing ethics into the electrical engineering classroom.

Importance of ethics in E&EE education

For many programs, the teaching of ethics within electronic and electrical engineering is based on codes of conduct or codes of ethics (see Chapter 5). This is unsurprising, as many of these codes are linked to professional bodies – and often to the accrediting bodies that will evaluate the content of courses (see Chapters 32–36 for more on accreditation). As such, these codes provide an interesting starting point for discussing ethics within the electrical engineering curriculum.

In our realm, the best known of these is the IEEE Code of Ethics (IEEE, 2020), which provides a normative ethical framework of both consequentialist (e.g., those relating to health and safety) and deontological (bribery and corruption) positions. These are spelled out in even more detail in examples from the National Society of Professional Engineers (NSPE) Code of Ethics for Engineers (NSPE, n.d.). Chapter 2 identifies and defines a wide range of applicable theoretical frameworks.

Many professional engineering institutions have produced similar statements of ethics and professional values worldwide. However, they typically apply to the engineering profession in general rather than to electronic and electrical engineering specifically. The Association of Computing Machinery (ACM) (2018) emphasizes several issues of particular importance to those in computing systems – a topic that has considerable overlap with E&EE (e.g., issues related to privacy, issues when modifying or retiring systems, and systems that become integrated into the infrastructure of society) – and identifies relevant ethical and professional codes. In the UK, the Institute of Engineering and Technology (IET) (2019), formerly the Institute of Electrical Engineers) also produces a rules-of-conduct document and in it (in keeping with rules of conduct), ethics and professional codes are combined. Codes in the E&EE realm frequently include considerations for upholding the image and reputation of the engineering profession; for example, the IET (2019, p. 3) specifies that "Members shall neither advertise nor write articles (in any medium) for publication in any manner that is derogatory to the Institution or to the dignity of their profession."

Although professional bodies are often considered the bastions of professional standards, they face their own ethical challenges. For example, a lively debate ensued when the IEEE announced that they would ban Huawei scientists as reviewers in their publications in response to legislation within the United States (Mervis, 2019). This highlights that while we usually consider that codes encompass moral binarism, stating clear and delineated positions on professionalism and professional ethics, applying and upholding them is far more complex. As we will explore later in this chapter, some of the most interesting applied moral discussions invoke an element of moral relativism in forming personal ethics. (For more on moral development theories, see Chapter 10. For more on relativism, see Chapter 28 on epistemological development.)

Although the professional bodies oversee frameworks for the engineering profession, it falls to accrediting bodies to distill these codes into required learning of professionally accredited programs. These typically follow the specifications set out by the Washington Accord (International Engineering Alliance, 1989) and are all relatively similar in scope and coverage, as seen in Chapter 32.

Approaches to ethics in E&EE education

Historically, electrical and electronic engineers have been involved in ethics education. Many engineering ethics textbooks have been written by electrical engineers, including those by Martin and Schinzinger (1996; Martin is in philosophy and Schinzinger in E&E engineering), Unger (1994), Fledderman (2008), and Baura (2006). Joseph Herkert, another E&E engineer, collaborated on a review of engineering ethics that included a section on education (Barry & Herkert, 2015). Herkert also edited a volume on *Social, Ethical, and Policy Implications of Engineering* (2000) that drew from work conducted in the IEEE Society for the Social Implications of Technology. The Society publishes the *IEEE Technology and Society* magazine, which often includes work related to ethics (IEEE Technology and Society, n.d.).

Colby and Sullivan (2008) published a review of approaches to engineering ethics education that focused on standalone courses in ethics (taught by engineering or other faculty), discussion of professional responsibility (often tied to codes of ethics), and modules (typically delivered within two or three class periods). Colby and Sullivan based their work on in-person visits to undergraduate programs in mechanical and electrical engineering at universities in the United States. We use Colby and Sullivan's categorization of discussion of professional responsibility tied to codes of ethics, standalone courses, and modules to frame our review of the literature in this section.

Discussion of professional responsibility tied to codes of ethics

In their teaching, faculty members in E&EE have incorporated discussions of professional responsibility tied to codes of ethics (often the IEEE Code of Ethics). They often incorporate these codes when discussing case studies that fit into one class period. This type of discussion, or content presentation, could be facilitated at any level of study; therefore, we provide examples below from Master's courses and (first-, third-, and fourth-year) undergraduate courses.

The literature shows that discussions of professional responsibility may be specifically focused on the IEEE Code of Ethics. In a project-based course titled 'Electric Power Engineering' for Master's students at Chalmers University in Sweden, Ehnberg et al. (2022) helped students tie the IEEE Code of Ethics to their specific projects. Students used the code as a tool to identify ethical dilemmas or risks for their project and then explored ways to avoid these dilemmas in their final reports. To illustrate, in a project that was designing an electrical brake for a wind turbine, students considered the ethical canon of "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" (Ehnberg et al., 2002, p. 2) from the IEEE Code of Ethics. Students identified a risk/dilemma of the brake system failing in strong winds and described preventive action of making sure to be well aware of the safety issues related to installation; students highlighted these in their report. After this experience, the students reported that they believed the IEEE Code of Ethics was relevant to their projects and future careers. Ehnberg et al. (2022) stress the importance of focusing on discussion with real-world examples. An interesting aspect of this research is that the interventions were done in-person, online, and pre-recorded; all three approaches had similar outcomes in terms of student engagement and responses to questions about the relevance of the codes to their projects, suggesting that instructors have flexibility in how they choose to implement such work.

Some discussions of professional responsibility focus on case studies and use the codes of ethics to suggest ways to analyze or move forward. Clancy et al. (2005) developed a module for one 3-hour laboratory period for a first-year module on circuits at Worcester Polytechnic Institute in the United States. Students examined case studies on engineering ethics drawn from internet resources (National Institute for Engineering Ethics, n.d.). Case studies were chosen to be relevant and easily understood by first-year students but not to be specifically relevant to E&EE topics. Students learned about and used the IEEE Code of Ethics to suggest action plans. Data collected from focus groups indicated enhanced student awareness of ethical issues. The authors provided useful advice for others interested in incorporating ethics into their classes. They believe that the adoption of the program by other faculty members was made easier due to the availability of an unused laboratory period in the first week of the term. Materials were also provided, and one of the authors assisted the instructor during the first offering of the program.

Ekong (2015) developed a module for teaching ethics that could be incorporated into any E&EE undergraduate course using case studies from electrical and computer engineering practice and exposure to codes of ethics from the IEEE, IEEE Computer Society, Association for Computing Machinery (ACM), and National Society for Professional Engineers (NSPE). Ekong implemented this intervention at Mercer University in the United States in two 50-minute class periods in a third-year microcontroller class with introductions, case studies, assignments, and quizzes. Ekong stressed the importance of having an electrical engineering faculty member lead the instruction because "a student is more likely to relate to the topic, e.g. Engineering Ethics, if that topic is taught by a professor in the student's discipline" (p. 1). Ekong chose E&EE-related case studies because the case studies "in ethics courses are usually taken from mechanical and civil engineering disciplines. Electrical and Computer Engineering (ECE) students may have difficulties relating to these cases" (p. 1). The case studies from NSPE focus on E&EE topics: software security, quality of products (defective chips), copyright (using unlicensed proprietary software to create a new software product), and compliance with ADA guidelines. Students must connect the specific NSPE code of ethics to the case study (NSPE, n.d.). (See Chapter 18 on ethical issues in software engineering for more on this realm.)

Another example of case studies tied to the IEEE Code of Ethics has been implemented in several capstone design courses within electrical engineering. Motivated by the desire to incorporate achievement of ABET (2000) Student Outcomes related to ethical responsibility and contemporary issues, Jiménez et al. (2006) developed a 2-hour module on 'Social and Ethical Implications of Engineering Design,' which aims to help students "reflect on issues and challenges associated with (i) professional integrity, (ii) engineering, industry and social responsibility, and (iii) technological impact, societal and global awareness" (p. 1). This module was incorporated in capstone courses in various areas of electrical and computer engineering taken in the last year of undergraduate study at the University of Puerto Rico-Mayagüez. The 2-hour module included an introduction to ethics, a discussion of professional integrity in engineering, and a consideration of ethical frameworks, including the IEEE Code of Ethics. Each course featured a case study relevant to the topics of that capstone course in the discussion of integrity in engineering. For example, in the 'Communication System Design: Signal Processing' course, the ethics case study centers on digital rights management (DRM) and the tension between consumer rights and the right of companies to protect their digital content. In the 'Communication Systems Design: Circuits and Antennas' course, the ethics case study considers the health hazards of electromagnetic waves – focusing on the high-power radio transmission towers in Cesano, Italy, and their impact on the local community (Hellemans, 2005). Jiménez et al. (2006) reported that students who responded to surveys at the end of the courses were positive about the impact of these modules on their own development. All students said it was very important for 'ethics to be integrated into engineering courses.' Over 80% indicated that the module had a high impact (5/5) on their 'willingness to be guided by ethical principles in professional work' and 'to be alert to and sensitive to ethical problems.' However, only 60% strongly agreed that others would be motivated to act ethically due to this module. In their comments, students expressed a desire for more opportunities to practice using ethical principles in their electrical engineering designs and curricula.

Standalone courses on ethics taught by E&EE faculty members

Passino (1998) provided an example of using Martin and Schinzinger's (1998) textbook to support the teaching of professional and ethical aspects of E&EE to a class of 120 students at Ohio State University in the United States. This example is primarily an ethics class taught by an E&EE faculty member but not focusing specifically on E&EE topics. The course was intentionally placed in the final year of the curriculum in hopes that most students had already worked on an engineering job and could bring this experience to the discussions. The main topics were "(1) safety and risk with case studies; (2) engineering as social experimentation and its link with design with case studies; and (3) professionalism and organizational issues with case studies" (Passino, 1998, p. 274). The author recommended avoiding:

> spending too much time on ethical theories at the expense of getting the students to debate case studies (engineering students tend to identify much more closely with case studies and become convinced of the importance of the material easier than via ethical theories). It is important to make some connections between technical design issues in engineering and safety, risk, ethical, and professional issues. Certainly, some time should be spent on codes of ethics.
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> *(Passino, 1998, p. 274)*

At the University of Illinois at Urbana-Champaign in the United States, Michael Loui created an elective course, 'Engineering Ethics,' for third- and fourth-year students studying electrical and computer engineering (Loui, 2005). The course emphasizes "ethical issues in engineering including professionalism, responsibility, confidentiality, conflict of interest, risk and safety, relationships between engineers and managers, loyalty, whistle-blowing, codes of ethics, licensing, and choosing a vocation" (Loui, 2005, p. 384). Loui specifically chose case studies related to E&EE, such as the Bay Area Rapid Transit (BART) case, where technical problems arose from the electronic sensors, electrical signaling, and software controls. The BART case is historically important because it was the first and only time that IEEE filed an amicus brief in support of whistle-blowing engineers (Unger, 1973). Loui found that students benefited from cases of actual incidents and activities that included discussions with diverse perspectives.

Modules integrating ethics in electrical engineering curricula

Colby and Sullivan's recommendations for engineering programs to better prepare students for "the ethical-professional dimensions of their work" (2008, p. 335) include (1) defining ethics and professional responsibility broadly specifically going beyond codes of ethics; (2) integrating with other learning goals; and (3) using active pedagogies, since professional responsibility includes skills and habits in addition to knowledge. Current efforts to incorporate ethics into electrical engineering curricula follow these recommendations; they integrate ethical issues related to electrical engineering into required courses where the ethics are tied to technical learning outcomes using active pedagogies and not directly tied to the IEEE Codes of Ethics. This is consistent with the pioneering work of Donna Riley, who developed a handbook on thermodynamics that provided specific examples of tying social and ethical content to technical content (Riley, 2011).

Below, we summarize such efforts in E&EE for the standard electrical engineering courses of 'Introduction to Circuits' and 'Controls Systems.' We also provide some guidelines for doing this type of work and examples of student responses.

Circuits class

The 'Introduction to Circuits' class is typically the first course that students in electrical engineering that students majoring in EE&E encounter. It is a required course for students in other engineering disciplines as well. It is often taken in the second year of the curriculum. Finding ways to incorporate ethics into this course has powerful implications for students seeing the relevance of ethics to the field of E&EE.

Conflict minerals: Lord et al. (2018) incorporated a module on conflict minerals into the 'Introduction to Circuits' course at the University of San Diego in the United States. Conflict minerals include tantalum, tin, tungsten, and gold mined in areas such as the Democratic Republic of the Congo (DRC) where the money from their production supports armed conflict. The module was designed to connect conflict minerals' ethical implications to capacitors, a typical topic in this course. Learning objectives included:

- Analyzing capacitors as electrical devices
- Defining conflict minerals and describing at least two social issues surrounding them
- Describing where conflict minerals are used
- Describing potential options for engineers concerned with societal implications of conflict minerals

Before the module, students completed calculations about tantalum (Ta) in capacitors and cell phones and identified where Ta is mined. During the in-class module, the instructor defined and introduced some history about conflict minerals. Students discussed conflict minerals and their societal and ethical implications and brainstormed ways to reduce reliance on conflict minerals as engineers. For homework after the module, students were each assigned a well-known company. They researched the company's conflict-minerals policies and presented their findings to classmates in a subsequent class. Students were asked to highlight social implications and concerns about these strategies. Additional modules explored electronics recycling and sustainable innovation (Lord et al., 2018).

*EV batteries and circular economy:*In another module for 'Introduction to Circuits,'students explore electric vehicle (EV) batteries, tying them to the technical topic of voltage dividers which is typically covered in this class and the concept of the circular economy, where products are reused or recycled for as long as possible (Judge et al., 2022; Lord & Finelli, 2023). Learning objectives include:

- Designing a voltage divider for a DC source to illustrate repurposing EV battery packs
- Estimating energy available in end-of-life EV batteries
- Describing societal risks introduced by recycling EV batteries that could be alleviated by applying circular economy principles

Instructional activities include listening to a podcast about the circular economy and answering questions, estimating the energy demand existing end-of-life EV batteries could meet, discussing how the circular economy relates to circuits' concepts and EV batteries, and discussing ways to use the circular economy to repurpose batteries. For example, batteries no longer suitable for EVs could be used in residential solar energy systems. Exercises for homework include designing a voltage divider to provide a specific output voltage from a repurposed EV battery and exploring the effect of energy degradation on EV battery repurposing. The module helps students explore the ethical issues of the circular economy as an alternative to the traditional economy, how engineering design is connected to the end of product life, and electric vehicles and sustainability.

Lord and Finelli (2023) are working on a US National Science Foundation (NSF) grant to incorporate sociotechnical modules, including ethical considerations, into the 'Introduction to Circuits' course. They will implement the conflict minerals and EV batteries modules in larger classes and develop more modules (Finelli & Lord, 2023). They are recruiting partners who teach 'Introduction to Circuits' in other universities to implement these modules elsewhere.

Controls class

The concept of social justice can be an interesting way to incorporate ethical considerations into electrical engineering courses. Researchers at the Colorado School of Mines in the United States incorporated social justice concepts in an 'Introduction to Feedback Controls' (IFCS) course/module (Johnson et al., 2015; Leydens et al., 2021). The course is for electrical and mechanical engineering students and is taken as a technical elective in students' third or fourth year of undergraduate study. The interventions related to social justice included a guest lecture by a faculty member from social sciences focused on the 'Engineering for Social Justice' (E4SJ) criteria (Leydens & Lucena, 2018) and a reading from Riley's (2008) *Engineering and Social Justice* book on mindsets in engineering. As Johnson et al. (2015) state, "Social justice defies a universal definition, but is related to the vision that people and communities have the right to equality (in various senses), to health, to dignity, and to opportunities" (p. 1). Thus, social justice considerations for engineering often explore ethical questions of impact. The authors provide an example of modern agricultural machinery where:

> Advanced control systems have made crops more affordable. These same systems have reduced the sustainability of the family farm, significantly changing the agricultural lifestyle, which has had far-reaching implications on rural communities and their economies. Thus, for engineering practice, a social justice framework encourages exploration of the following questions: In the short and long-term, from engineering designs, models, and other interventions, who benefits? Who does not benefit? Who suffers?
>
> *(Johnson et al., 2015, p. 2)*

In the controls class, instructors presented what they called 'social justice' examples that connected the controls' topic of resonance to the safety implications of an unbalanced washing machine and issues related to wind energy systems and active prosthetics. Homework problems were rewritten to include social considerations. For example, a problem about a water tank with no context was rewritten to explicitly ask students to balance protecting the pump, ensuring enough water for a village's needs, and not wasting water by overfilling. Using focus groups, the researchers investigated students' responses to incorporating this content in courses where the social justice content was made visible (Group A) compared to the traditional approach where the social justice content is not visible (Group B). Their results indicated that some students valued incorporating ethical topics into this technical class while others did not. Many students focused on social justice as related to "individual ethics or responsibilities but did not recognize the obligations of the broader group of professional engineers to society" (Leydens et al., 2021, p. 740). The findings highlight the importance of integrating ethical considerations into multiple classes since one class is insufficient to help students learn to deal with the complexity of ethical issues and develop robust ethical knowledge and ideas.

Pedagogical guidelines and student responses

Incorporating ethical issues effectively in electrical engineering classes is challenging for many reasons. The instructor's identity can come into play because those educated with a deep technical focus may not feel prepared to engage in discussions about ethics or venture into challenging topics related to race, gender, and so on. Instructors need some degree of comfort in dealing with ambiguity, which differs from how most technical work is taught (for more on this, see Chapter 28). For example, there is a 'right' answer to calculating the voltage at the middle of a voltage divider but no 'right' answer to the question: *Should I get a new cell phone every year now that I know the impact on people's lives?* Learning these ethical concepts by doing only mathematical problems is impossible. On the other hand, ethical issues can be incorporated using collaborative methods such as discussions and active learning (Colby & Sullivan, 2008; Loui, 2000). (Please see Chapter 25 on reflective and dialogical approaches in engineering ethics education.) It is also important for instructors to follow good pedagogical practices, including having clear learning objectives and assessments (see Chapter 29). Gelles and Lord (2021) proposed a framework for integrating sociotechnical content into engineering classes that might also help teachers consider integrating ethical content, which is sociotechnical. The (Gelles & Lord, 2021) framework involves the following steps:

0. Identify possible sociotechnical collaborators.
1. Identify a salient course topic that has broader social and environmental implications.
2. Identify, add, or update existing course learning objectives and/or the ABET student outcome(s) that this sociotechnical course topic aligns with.
3. Create learning objectives for specific sociotechnical modules.
4. Create modules by designing activities for homework before and/or after class session(s) and class session(s) that integrate technical content and calculations students are familiar with and social and environmental context.
5. Include low stakes assessment for the module (e.g., homework) and consider including sociotechnical questions on exams.
6. Conduct formative assessment and/or engineering education research on sociotechnical modules to get student input and improve module offerings in the future.
7. Refine modules and identify possible sociotechnical collaborators for the next course offering.

In contrast to some efforts to include ethics, which are met by resistance among engineering students, this integrated approach with modules tied to technical content has been shown to be appreciated by students. Students see ethics as 'real world' engineering and beneficial for their learning. For example, after the conflict minerals module, students participated in surveys and interviews (Lord et al., 2018, 2019). In the survey, all students who responded said the topic mattered to them as engineers. In the interviews, several students pointed out that these topics were not typical for engineering classes and that they found them engaging and would like to see more of this.

> *I thought it was a really interesting topic that has larger social consequences. It was cool to get away from the stigma of engineers only worrying about math and showing that engineering is able to have effect in other disciplines.*
>
> *(Lord et al., 2019, p. 5)*

The experience helped some students see connections between their personal and professional lives as ethical engineers.

> *Prior to this class, I did not even know what conflict minerals were or where they were used. The in-class group presentations on this topic were especially relevant because I researched on Samsung, while having a Samsung phone. I learned that non-conflict tantalum and tin are used in the circuitry of my cellphone. In the future, I can apply this knowledge as an engineer (in design) and as a consumer (in purchasing from companies that have specific procedures for dealing with conflict minerals).*
>
> *(Lord et al., 2019, p. 11)*

In the interviews, students indicated that they found modules to be well-integrated into the class. When asked about engineering as a field, every student brought up the modules, emphasizing that they saw the ethical context as important for developing their sense of engineering in the real world and its potential. It did, however, challenge some students' definition of 'engineering' as indicated below:

> *Obviously, we looked at a lot of stuff that wasn't engineering including the conflict minerals, and the Sunshine Box which I thought was really cool. And that was very clearly … I mean it was engineering but at the same time it was very clearly like looking at it from different angles.*
>
> *(Lord et al., 2019, p. 12)*

One measure of the success of these modules is that a student specifically recommended keeping them and even expanding them because they were beneficial for learning as "*real examples of how the things worked"* (Lord et al., 2019, p. 13).

In interviews that Lord and Finelli conducted after the EV battery module, students said that they found the module interesting, impactful, and relevant.

> *I came in hating electrical engineering, like it was just not for me. So I think like actually doing the voltage divider and using that for like sustainability purposes and the circular economy was really cool to like actually be like, okay, the stuff we're learning is like being used for something … I liked that part of it.*
> *… we are a part of the issue if we don't decide to fix it.*
>
> *(Lord & Finelli, 2024, p. 4)*

Opportunities for exploring ethical issues in electronic and electrical engineering

In considering ethics in E&EE, there are many opportunities to explore issues that have not been explored in the literature. In this section, we begin with some issues that could easily be included in a technical class to align ethical discussions with the delivery of electronic and electrical engineering content. As highlighted above, although there are some publications in these areas, they have not all focused on the pedagogical implementation of discussion of such issues in the electrical engineering classroom. In the subsequent section, we identify topics specific to the culture of electronic and electrical engineering that may provide useful talking points for instructors who are comfortable leading discussions of sensitive ethical issues. Both sections provide instructors with ideas regarding ethical considerations they could use with students. We encourage electrical engineering educators to take up the challenge of doing this important work and explore how to directly connect consideration of ethics with the technical electronic and electrical engineering content they are teaching and the culture in which they are embedded.

Broad issues for future E&EE curricula

This section provides some examples of ethical issues that could be covered in electrical or electronic engineering classes in Table 16.1. For each, we include an example of a potential reading that might be introduced in the class. These are examples for future development, not citations of work reporting curricular interventions.

Ethical issues in the culture of electronic and electrical engineering

In addition to tying to technical issues, we encourage readers to look locally and consider the culture of E&EE and how implicit and explicit aspects of the academic and professional culture can impact students in the E&EE classroom. *What messages do engineering educators send by the language that we use?* Here, we discuss some terms prevalent in E&EE that can adversely impact the sense of belonging for many people, including women and students of color: the language of master/slave, male/female connectors, resistor codes, and the 'Lena' photograph used in digital image processing (an area within electronic engineering). These are opportunities for E&EE instructors to identify their own potential blind spots and explore relevant ethical issues with their students in classes. This is probably more challenging than the sociotechnical integration we call for in the previous section. We suggest a pedagogical approach for having these discussions at the end of this section as well as some important considerations for educators who want to take on the challenge of doing this work to change culture.

Technical jargon

Taheri (2020) explains the importance of language as

> one of the most powerful tools we have as humans that incorporates personal assumptions, social norms, and cultural ideologies. It is therefore important to consider language critically and to watch for biases in usage. Language reflects the world it is used in, but it is also active in maintaining or redesigning that world. It can be a tool of discrimination or of empowerment.
>
> *(Taheri, 2020, p. 151)*

Taheri goes on to review some discriminatory and non-inclusive language in science, technology, engineering, and mathematics (STEM) fields to raise awareness and suggest alternatives. Two of these examples are particularly relevant to electrical engineering and are discussed further here.

Master/slave: Historically in E&E engineering, the phrase 'master/slave' is used for digital designs where one section of software, hardware, or firmware, the 'master,' controls another, the

Table 16.1 Ethical topics that could be integrated into E&EE classes

E&EE Topic/ Class	*Summary of ethical issue*	*Supporting material/ case material*
Electro-magnetics	There have been numerous news reports expressing concerns about the abundance of electromagnetic energy sources, primarily for communication but also power lines, and their effect on human health. Although the risk is low, there is evidence that it is not entirely non-existent. Engineering class discussions might consider what level of risk is acceptable, who should decide, and potentially even link to technical evaluations such as the power from a mobile phone mast at a distance over the power from the phone itself.	Examples – Ghorbani et al. (2018); Reading – Hardell and Sage (2008)
Integrated circuit design	Instructors could structure a case study (Chapter 20) and facilitate reflection and discussion (Chapter 25) around the responsibility to disclose to customers information on flaws in the design of an integrated circuit (IC), the Intel Pentium Processor. Students can be prompted to consider the company's responsibilities and ethical position on releasing potentially damaging details to the users of its products.	Example Fleddermann (2000); Reading Crothers (1994)
Electronic design	Consumer electronics have developed to a position where typically, repair is not possible. If a significant fault occurs, replacement and disposal are the only options. Recently, a global movement backed by legislation on the 'right to repair' has sought to reverse this. The aim is to require manufacturers to design in the possibility for repair where possible. However, doing this is not always easy and may have unintended consequences. Cunningham and Hobbs (2023) may be used for a debate on how far 'right to repair' should go and where it is appropriate.	Reading – Cunningham and Hobbs (2023); O'Reilly (2020)
Off-grid, smart-grids, and renewable energy	The topic of electricity supply is a rich area for discussions that links ethical and sustainability considerations with technical evaluation. Exercises may ask groups to consider energy supply in a remote area, where considerations about the users are as central to the engineering design solution as the technologies available. The design could be supported by energy usage monitoring and discussions of available materials to minimize environmental impact.	Example – Louie (2018)
Image technology and privacy	With the growth of imaging and security technologies come potential privacy issues. Harrington (2014) highlights the level of intimate detail that can be observed. Engineering class discussions could consider how privacy and security could be balanced, and if alternative technologies might be possible to increase security while preserving privacy.	Reading – Harrington (2014)
Weapons systems	Many electronic engineering employment opportunities can be found in the military and defense sector and its supply chains. This is an ideal opportunity for a discussion on personal ethics and how each person must use their own moral compass to determine where they feel comfortable. Some may feel perfectly fine working on autonomous weapon systems, whereas others would refuse this type of work. Chapter 15, on ethical issues in mechanical and aerospace engineering, discusses such dilemmas in detail.	Reading – Hersh (2022)
Wireless systems class	Apple Airtags have a wide range of useful and innocuous applications, yet they have also raised security and privacy concerns. *What responsibility do technology companies have for the unintended uses of their products? Is it on firms to consider the implications and produce 'fixes' that reduce potential harm?*	Reading – Roth et al. (2022)

'slave.' The use of this terminology began in 1904. Eglash (2007) explored the term's history, its relationship to racialized social connotations, and why it is so popular in engineering, and then posed recommendations for alternatives. In 2004, this term was listed by the Global Language Monitor (Reuters, 2004) as one of the most politically incorrect terms of the year. In the wake of the 2020 murder of George Floyd in the United States and the heightened awareness of systemic racism, stronger calls have emerged for the elimination of this terminology including by students (Steele, 2020), EE professionals (Ellis, 2020), and the media (Canales, 2020).

> Santiago Gomez, a graduate student in computer engineering, was so perturbed when he encountered the terminology in a textbook – *Digital Design, 6th Edition* – for his Logic Design course … that he wrote to the textbook's publisher, Pearson, calling for the language to be changed.
>
> *(Steele, 2020, p. 2)*

Alternatives have been proposed and adopted. For example, in 2021, Microchip issued a product change notification that listed "1) Replaced terminology "Master" and "Slave" with "Host" and "Client" respectively" (Microchip, 2021, p. 1). It is interesting that the reason for change stated was "To Improve Manufacturability" (p. 1). Other proposed alternatives include 'leader–follower,' 'primary–secondary,' 'writer–reader,' 'primary–replica,' and 'coordinator–worker' (Taheri, 2020, p. 153).

Danowitz and colleagues (2021) investigated the importance of this terminology for student inclusion and belonging at an undergraduate predominantly white university in the United States. They found that "42% of students surveyed either agree or strongly agree that use of master–slave terminology is problematic, including 100% of female and 100% of African American students, and that the use of the terminology may create conditions to evoke Stereotype Threat" (Danowitz et al., 2021, p. 1). The authors also critiqued the usefulness and accuracy of the terminology for learning.

Male/Female connectors: Traditionally, connectors used throughout E&EE are referred to as 'male' and 'female,' referring to whether they have a plug or a socket. As described by Wikipedia, "the female connector is generally a receptacle that receives and holds the male connector" (Wikipedia Gender of Connectors, n.d., ¶ 1). Wikipedia has a long entry on this topic, which conflates gender and sex, does not critique or suggest problematic aspects of this terminology, and provides detailed descriptions of hermaphroditic connectors and gender changers. This terminology can be seen as reductionist, reducing gender to physical attributes as well as being uncomfortable in terms of its focus on sexual intercourse with the joining of these connectors called 'mating.' This terminology also can be seen as unnecessarily sexualizing and enforcing a heteronormative narrative. Wikipedia lists plug, pin, and prong as options for 'male' connectors, and receptacle, socket, and slot for 'female' connectors (Wikipedia Gender of Connectors, n.d.). Various creative alternatives to 'male' and 'female' have been proposed such as 'worm–apple,' 'pen–cap,' 'bottle–cork,' and 'sword–sheath' (Eveleth, 2015) or 'outie–innie' (Pearlstein, personal communication, 2019).

Resistor codes

Another problematic aspect of the culture of E&EE is the mnemonic code or phrase used for remembering the resistor color code. In 1961, Alan Dundes wrote a paper exploring the richness of mnemonic devices as examples of folklore in various fields where he flatly states the following for 'resistor code reminder' (1961, p. 41). Although the language is horrifying, it is sometimes used by educators today, and to show what students over the past half century have been exposed to, we quote Dundes' explanation:

> This device gives the resistance in ohms of a coded resistor. The code is: Black (0); Brown (1); Red (2) ; Orange (3); Yellow (4) Green (5); Blue (6); Violet (7); Gray (8); and White (9). 0 1 2 3 4 5 6 7 8 9 (ohms) B B R O Y G B V G W (colors). Thus if a resistor had a red, a green and a black band, the resistance would be 2, 5, and 0, that is, 250 ohms.

The mnemonic device:

> Bad Boys Rape Only (Our) Young Girls But Violet Gives Willingly.
> Black Boys Rape Our Young Girls But Violet Gives Willingly.
> Bad Boys Run Our Young Girls Behind Victory Garden Walls.

There is no commentary in the Dundes (1961) article on the sexist or racist nature of these devices. One example of the impact of such codes is depicted in *Violet Gives Willingly*, a documentary film about a woman "confronting troubling memories of her short-lived career as an electrical engineer" (International Documentary Association, n.d., ¶ 3) in 1974 (Sanford, 2022). As a woman studying E&EE in the 1980s, one of us (Susan) was horrified by the codes she heard as an undergraduate student and did not want to commit them to memory due to the references to misogyny and rape.

Yet Dundes' (1961) mnemonic persists. A recent search we authors conducted for 'resistor color codes' using Quora[1] turned up a range of possibilities including some of the ones above. A more recent website suggests using a less offensive but still gendered pneumonic device "Bright Boys Rave Over Young Girls But Veto Getting Wed" (WikiHow, 2023). A response to the query we ran using ChatGPT in February 2024 on "What are several mnemonics for the resistor color code," provided "Bad Boys Ravage Our Young Girls But Violet Generally Wins" as the first option and the one with "Violent Gives Willingly" fifth.

Recently, the first author of this chapter, Susan, briefly referenced the resistor mnemonics in class, and several students (white women and men of color) stopped her and asked for more explanation. Developing a discussion around this topic could be a rich experience for E&EE students and faculty. However, we recognize that not all educators will have the skill to facilitate such an explicit discussion with undergraduates, but they can work to develop such skills to help E&EE education and culture evolve.

Image processing

Sometimes, what might seem innocuous and commonplace in a technical community may have a more problematic backstory. One such example is the Lena (or Lenna) image. If you have ever looked into work on image processing or image compression standards such as JPEG, you will likely have seen this image – a 512 x 512-pixel image of the face and upper arm of a young woman in a straw hat with a blue feather turning to look over her shoulder towards the camera. The image is of Swedish model Lena Forsén (Söderberg), but what is perhaps not so commonly known is that the complete image (of which a cropped area from the top portion of the origin photograph is the widely used test image) first appeared as a nude centerfold in the November 1972 issue of 'Playboy' magazine. The image was used by the Signal and Image Processing Institute (SIPI) at the University of Southern California for comparative tests between compression algorithms but has now become ubiquitous within the image processing community. It is argued that the widespread use of an image from what many consider to be a pornographic source only serves to reinforce the underrepresentation of women in computer sciences and engineering (Culnane & Leins, 2019), including by Lena herself, as she stated in the 2019 short film *Losing Lena* (Bartley, 2019).

It is of particular interest how the male-dominated culture of the technology and computing industry has served to not only normalize the use of such an image over many years but continues to do so even to this day. As a journal editor, the second author, John, recently found himself in an altercation with an eminent professor of computer science at a top US institution over his suggestion that alternative images would be far more appropriate. This exposes a potentially interesting debate with students on several fronts, but mainly around why the provenance of such an image matters and how it impacts the drive for diversity and inclusion with engineering and tech. It is now common for journals to advocate for the use of alternative (and arguably technically better images) such as 'Cameraman,' 'Mandril,' or 'Peppers,' and some, such as 'Nature Nanotechnology,' have stated that they will automatically reject submissions using the 'Lena' image (Nature Nanotech, 2019).

In November 2023, decades after the image first appeared, the IEEE officially adopted this policy citing ethical reasons.

> IEEE's diversity statement and supporting policies such as the IEEE Code of Ethics speak to IEEE's commitment to promoting an inclusive and equitable culture that welcomes all. In alignment with this culture and with respect to the wishes of the subject of the image, Lena Forsén, IEEE will no longer accept submitted papers which include the "Lena image".
> *(IEEE Author Center Magazines, 2024)*

Moving forward

Hopefully, this offensive language is not taught to students in today's E&EE classrooms. We might prefer not to state language such as the resistor codes at all in hopes that they will die out. Yet, today, the tradition is still alive online, and addressing it as an ethical issue is essential to changing the culture. Discussing such issues with a critical eye as to how they have contributed to and been reflective of the culture of E&EE is difficult but important work. It is worth noting that E&EE continues to have a very low representation of women compared to other disciplines in both the United States (Lord et al., 2015, 2019) and the United Kingdom (Bellingham et al., 2023). Educators need to do more to identify and address cultural factors pushing women and people of color away from E&EE studies and careers. To confront ethical issues in E&EE related to language, belonging, and discrimination, we encourage E&EE educators to reflect on their own language choices. Educators can develop skills in discussing these sensitive topics by educating themselves; talking with colleagues outside of engineering in fields such as sociology or ethnic studies or education; discussing these issues with colleagues, friends, and graduate students; and then introducing them to undergraduate students. We recognize that some dangers exist for raising sensitive topics in class, particularly for students and instructors from vulnerable minoritized groups. Instructors must carefully navigate these discussions, ensuring a safe and inclusive learning environment while addressing the historical and contemporary issues in the field. Chapter 25 on reflective and dialogical teaching approaches may be a helpful resource.

The University of Washington Information Technology group has a website with an Inclusive Language Guide, which contains information regarding problematic terminology in information technology, including 'master–slave,' 'male–female' connectors, and others such as 'blacklist-whitelist' and 'blackhat/whitehat.' This is a good resource for exploring technical terminology and why it can be considered problematic (UW-IT, 2023).

A pedagogical strategy that might be helpful for educators who want to lead discussions of these ethical issues is the confront-address-replace (CAR) framework. According to Asfaw and colleagues,

> The CAR Strategy is meant to be a proactive and modern pedagogy which encourages discussion and thought on whether or not we should replace questionable aspects within engineering. The CAR Strategy does not force students to replace 'master–slave' or any terminology from their vernacular – it simply welcomes it.
>
> *(Asfaw et al., 2021, p. 25)*

Specifically, this CAR strategy involves *confronting* the historical significance of a term such as 'master–slave.' The strategy then moves to *addressing* the inaccuracies of this problematic terminology. Finally, the discussion turns to recommendations for alternatives to *replace* the problematic language, although these are suggestions rather than prescriptions. Researchers have studied the impact of a CAR strategy as a teaching framework in computer engineering at a predominantly white undergraduate university focusing on 'master–slave' terminology (Asfaw et al., 2021). Over two-thirds of the students surveyed in that study agreed that this was an effective framework for eliminating offensive terminology and that they would like to see it used in other engineering classes where it is applicable. The researchers suggest that this strategy could be used for other examples of problematic E&EE terminology.

Conclusions

In this chapter, we have identified the importance and historic scarcity of case studies that are directly and technically relevant to students of electronic and electrical engineering. We have highlighted example topics where instructors can go beyond the typical professional subject of ethics and codes of conduct to introduce ethical issues. We have suggested discussion points and case studies that can be integrated in the core curricula and classes that form electronic and electrical engineering. We have also demonstrated that within electronic and electrical engineering there exists a number of contemporaneous case studies and issues that would make excellent discussion points within the technical classes of an electronic and electrical engineering program. These include sociotechnical cases where ethics trade-offs are a central consideration and issues of the culture and language within electronic and electrical engineering which can be directly linked to engineering content and bring the discussion of ethics into technical classes. We have presented cases that can provide active learning activities to breakup lecture classes by introducing participatory debates on topics directly related to the theoretical concepts under discussion. We consider that this explicit connection of ethical concerns with technical content is vital to engage students and allow them to see that ethics is not an afterthought or an irrelevant and abstract concern but central to good electronic and electrical engineering practice and best practice in electronic and electrical engineering design. We hope that instructors will find these cases useful and will be able to integrate them into their classes.

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Note

1 https://www.quora.com/Whats-the-best-way-to-remember-resistor-colour-codes

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