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ETHICS AND ENGINEERING DESIGN FOUNDATIONS

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Introduction

Engineering design is often considered central to engineering practice (van Gorp & van de Poel, 2001). According to Archer (1992) engineering design is "directed towards meeting a particular need, producing a practicable result and embodying a set of technological, economic, marketing, aesthetic, ecological, cultural and *ethical* values determined by its functional and social context" (p. 8). Devon and van de Poel (2004) claim that design is "quintessentially an ethical process" (p. 461), contending that "ethics is not an appendage to design but an integral part of it" (p. 461). The decisions made during engineering design are thus critical in determining an engineering artifact, process, or technology's impact on society. When examining modern design more broadly from a philosophical perspective, Parsons (2016) identifies three aspects of the process involving 'design ethics': (1) when designers face ethical issues applying norms and rules during design, (2) when choices are made regarding what is designed, and (3) when designs modify or change existing conceptions of ethics.

The social form of inquiry involved in design and the ill-structured nature of the problems has led to design being defined as a reflective practice (Schön, 1987), highlighting the importance of considering societal impacts and ethics in engineering artifact, process, and technology development. Engineering training, however, does not appear to adequately prepare students to assume professional and ethical responsibility for the societal impacts of technology; students and recent graduates often have difficulty connecting social consciousness with user needs. Considering user needs reflects a commitment to designing solutions prioritizing user well-being and satisfaction, ensuring that benefits are distributed equitably. This ethical stance fosters a sense of social responsibility. However, "engineering education has been described as characterized by a 'culture of dis-engagement' in which ethical and societal concerns are constructed as different from, and less important than, purely technical concerns" (Lönngren, 2020, p. 44). There is evidence that the nature of programs can diminish students' inclination toward ethical discourse. For instance, empirical analyses have revealed a decline in students' interest in public welfare as they progress through their education (Cech, 2014). Moreover, in a study by Tormey et al. (2015), the moral reasoning of Swiss engineering students appeared to diminish during a period of ethics instruction – something the research team attributed to a hidden curriculum that encourages students to adopt an epistemology-based application of established principles and laws.

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The approach taken by students when identifying customer needs is often limited to conducting surveys and organizing focus groups early in the process (Bairaktarova et al., 2016). Consequently, students tend to treat needs as a checklist of requirements to use as inputs in their design processes. To address this situation, there is a need for interventions that enable students to cultivate a more socially conscious level of understanding. This shift towards considering user needs aligns with essential engineering ethical principles such as honesty, integrity, and fairness in the design process.

While we recognize that the impact of engineering work has led to an emphasis on broader issues such as sustainability, social responsibility, and ethics, our chapter focuses explicitly on ethics in engineering design, acknowledging that these ethical considerations are a vital and distinct component of the broader societal concerns within the field of engineering. We outline the definition of engineering design before introducing ways to classify engineering design. The stages of the engineering design process are explained so that we may understand how ethics relates to each stage. We then discuss the ethical implications of the social nature of engineering design. The subsequent sections focus on teaching ethics within engineering design and various educational models we may use. Finally, we share insights from Science and Technology Studies (STS) and end the chapter with concluding remarks, recommendations, and future directions.

Before that, we outline the ways our positionality impacts our work. Our perspectives and insights, shared in this chapter, are enriched by our backgrounds and experiences. Having all come from engineering and science backgrounds, we acknowledge the need for engineering researchers to challenge the myth of objectivity in research. We, therefore, took part in an exercise to surface our interpretive lens, and a summary is shared to inform the interpretation of the chapter presented.

Diana, with nearly 15 years of experience as a design engineer and a decade dedicated to engineering education and research, embodies a strong commitment to addressing the ethical dimensions of engineering and nurturing a holistic perspective in the field. Throughout her industry career, she often encountered ethical dilemmas that the engineers involved seemed ill-equipped to navigate effectively. Diana's experience revealed that engineering solutions frequently fail to prioritize user needs; her realization of this led Diana to transition to academia, pursuing an advanced degree in engineering education. Her mission is unwavering – to educate the next generation of engineers with a strong ethical foundation and an innate ability to empathize with the end user. She seeks to address challenges impacting people's everyday lives, using her expertise to nurture and elevate the engineering profession.

Natalie has been an engineering academic for 4 years. During her academic career, she has started to question *who* and *what* engineering is for and who benefits from and suffers from the cost of engineering decisions. She takes a broadly philosophical approach and is inspired by STS ideas. She enjoys incorporating the social sciences into teaching, which partly results from a conflict between personal and professional identity. She now leans towards qualitative research approaches. Her motivation to participate in this work was to collaborate with those with different experiences and develop her knowledge further. She considers herself an expert neither in engineering nor ethics but is trying to navigate the interface between them.

Mauryn has been an engineering academic for 7 years. She has worked on refining the content and pedagogical approaches involved in teaching engineering design and professional skills, particularly to first-year undergraduate engineering students. She has considered philosophical and practical approaches to integrating themes around ethics, social responsibility, equity and inclusion, and responsible innovation into engineering design. Having completed a Ph.D. in engineering sciences, she sought to develop competence in education and social science research techniques to deepen her understanding of research-informed approaches to her work. This led to her undertaking a postgraduate engineering education degree, and she now uses the research skills she gained to support educational developments in the engineering curriculum. Although her expertise is broader than the focus presented in this chapter, it has served as a great learning opportunity and a valuable interfacing of knowledge between herself and her fellow authors.

Our chapter benefits from these perspectives, fostering a holistic understanding of ethics in engineering design that encompasses practical, philosophical, and ecological dimensions, thus providing a comprehensive view of the subject.

Engineering design: types of design and the design process

Design, according to Petroski (1998), is what most distinguishes engineering from science: "Design is a process through which one creates and transforms ideas and concepts into a product that satisfies certain requirements and constraints" (p. 5). Brey (2022) provides a fuller understanding of design, emphasizing that it is an all-encompassing term and a core activity of society, pointing to fields such as craft and applied arts, fine arts, architecture, and applied social sciences. In differentiating engineering design, he relies on the ABET definition: "the process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative), in which basic science and mathematics and engineering sciences are applied to convert resources optimally to meet a shared objective" (ABET, 2018, p. 5). Engineering design is thus considered an activity carried out only with specialized training (e.g., ideation through free-hand sketching, CAD modeling, prototyping), knowledge, and methods for applying this knowledge.

Types of engineering design

The engineering design process can manifest in several ways, resulting in various, although sometimes overlapping, types of design. According to van Gorp and van de Poel (2008), how engineers address ethical issues depends on the type of design process used, and it is thus useful to consider these typologies. Vincenti (1990, 1992) categorizes engineering design processes using two dimensions: hierarchy and type. Concerning the former, the degree of external constraint is larger for design processes lower in the design hierarchy as the higher levels pose constraints (e.g., dimensional constraints, or constraints concerning functionality) on lower levels (Vincenti, 1990). An example of this is provided by van de Poel and van Gorp (2006), who describe piping and equipment design for (petro)chemical plants as being at the lower levels of the hierarchy. The design process and the product and chemicals involved are at higher levels and are also within the control of the petro(chemical) company. Engineering firms contracted to design piping and equipment need to adhere to economic and practical (e.g., space constraints) requirements as well as safety codes, regulations, and standards, all of which place external constraints on the design. Fulfilling multiple requirements imposed by such constraints thus results in ethical questions such as: *What is safe enough?*

A design can then be considered either normal or radical. In normal design, both operational principle (Polayni, 1962), how the design works, and the normal configuration or "the general shape and arrangement that are commonly agreed to best embody the operational principle" (Vincenti, 1990, p. 209) remain the same as in previous designs. In contrast, in radical design, the operational principle and/or normal configuration are unknown. According to van Gorp and van de Poel (2008), most decisions made during normal design are based on regulative frameworks (e.g., minimum safety requirements). Frameworks can also be used during radical design; however, the absence of normal configurations and operational principles may mean they are less applicable. In these latter cases, decisions are primarily made based on design team norms. The DutchEVO has been described (van de Poel and van Gorp, 2006) as a radical design. Its lightweight design meant a standard configuration could not be used and this led to questions and discussions regarding how safety could be operationalized. Through such examples, the importance of such distinctions becomes clear in that they shift responsibility from the engineering community and society involved in the formulation of regulations to the individual design engineer, thus having implications for trust in engineering and its products.

Brey (2022) describes a similar dichotomy between routine design and innovative or creative design. He defines routine design as "design that proceeds within a well-defined state space of potential designs, where all variables, their applicable ranges, and the knowledge to compute their values are directly instantiable from existing design prototypes" (Brey, 2022, p. 32). This is contrasted with innovative or creative design, which ventures beyond these established parameters.

We can also categorize engineering design in several ways, such as original, adaptive, redesign, selection, product, and industrial (Dieter & Schmidt, 2021). Original design, which incorporates the use or application of novel technologies, requires the result (be that a tangible or intangible artifact) to be unique. In contrast, adaptive design modifies an existing solution to fulfill different requirements or applies it in a novel way. Re-design aims to significantly improve an existing design and tends to result in enhanced service, function, and/or capability. Many tangible designs use manufacturer-supplied components with specified properties, performance attributes, quality, and cost, with components selected based on required properties. While the terms 'product design' and 'industrial design' tend to be used interchangeably depending on the engineering discipline, their target markets differ. Both designs aim to design a consumer product to be sold – but whereas this is a primary goal of 'product design,' 'industrial design' focuses more on the interface between the consumer and the product. For example, in industrial design, the end user may not be the typical customer in the public market as its primary goal is to create enhanced designs for manufacturers. When these products are commercialized, the target market is a niche one, which, in turn, may have broader access to sell to the public.

We will now focus on the stages of the engineering design process and investigate how ethical principles apply at each stage.

The engineering design process

The engineering design process has several distinct stages with unique characteristics and challenges. It begins with identifying the problem and progresses through the development of solutions, prototyping, and testing. Van de Poel (2000) distinguished the following five points of ethical relevance during the engineering design process:

1. The formulation of goals, design criteria, and requirements and their operationalization.
2. The choice of alternatives to be investigated during a design process and the selection among those alternatives later in the process.
3. The assessment of trade-offs between design criteria and decisions about the acceptability of particular trade-offs.
4. The assessment of risks and secondary effects and decisions about the acceptability of these.
5. The assessment of scripts and political and social visions that are (implicitly) inherent in a design and decisions about the desirability of these scripts.

(p. 3)

The first stage involves choices regarding *what* problems we decide to solve and *who* benefits – decisions that Chan (2018) claims must "presume some fundamental ideas of what is a good or worthwhile life," with ideals "usually (being) tempered within the parameters of some acceptable rules or obligatory norms" (p. 186). Multiple stakeholders are involved in formulating design criteria, both by detailing specific requirements and through general legislation (van Gorp & van de Poel, 2001). While some see the role of engineers as morally neutral, their being responsible for finding the best possible technological solution within constraints, van Gorp and van de Poel (2001) argue that how something is designed influences who will use it and for what purpose. Again, making use of the DutchEVO example, van Gorp and van de Poel describe how design will determine the person's physical ability to drive. They explain that the relationship between the user and a product impacts emotional sustainability. Therefore, if people enjoy their car, they might use it more often, leading to unsustainable behavior.

Later stages of the process include concept design during which creativity can bridge opposing moral values (van de Poel & Royakkers, 2011). During this stage, we may use what Johnson (1993) refers to as moral imagination, "an ability to imaginatively discern various possibilities for acting in a given situation and to envision the potential help and harm that are likely to result from a given action" (Johnson, 1993, p. 13). For example, van de Poel and Royakkers (2011) describe a plan to close the Eastern Scheldt in the Netherlands after a flood disaster. Environmentalists and fishermen opposed the closure, and thus, ecological care and safety values were posed against one another. A storm surge barrier allowing water through, but that was to be closed when a flood threatened, was posed as a creative compromise balancing safety and environmental concerns.

The simulation stage involves ensuring concept designs meet design requirements and consideration for the desirable or acceptable level of reliability in predictions (van de Poel & Royakkers, 2011). Although prediction reliability is a methodological issue, the reliability of predictions is considered a moral concern depending upon what is at stake. For example, in the case of nuclear power plants, for which failure is catastrophic, reliability would be considered more important than in simulations associated with everyday devices.

The decision stage involves analyzing simulation results alongside original requirements to compare concept designs and determine trade-offs and compromises that need to be made (van de Poel & Royakkers, 2011). This is particularly significant when considering the multiplicity of stakeholders involved, which will be discussed further when considering trade-offs and introducing Constructive Technology Assessment (CTA).

During detailed design, the selected design is elaborated, and such ethical questions as the choice of materials and their associated risks and health/environmental impacts are addressed (van de Poel & Royakkers, 2011). The subsequent prototype development and testing involves moral judgments about the extent to which tests represent circumstances in which designs are eventually used.

Finally, the manufacture and construction stages involve considering ethical issues such as labor conditions, emissions, and use of hazardous materials (van de Poel & Royakkers, 2011). Engineers must consider the moral issues raised by risks and hazards of designs and make decisions concerning the acceptability of these risks. This process typically involves attempts to characterize the risks involved, for example by conducting a risk assessment that considers factors such as failure modes, exposure, consequences, and probability, followed by the need to answer an ethical question regarding the acceptability of risk. Van de Poel and Royakkers (2011) outline four potential ethical considerations: informed consent, whereby risks are seen as more acceptable if those at-risk consent to involvement in the relevant activity (e.g., an experiment); assessing whether advantages outweigh disadvantages; the availability of alternatives for the best available technology; and, finally, the distribution of risks and benefits. These methods assume risks can be, at least to some extent, predicted. However, there is an increasing need to focus on cases with uncertain hazards associated with new technology. In such cases, the precautionary principle, which originated from the Rio Declaration (United Nations, 1993), is proposed. Sandin (1999) defines its four dimensions as threat, uncertainty, action, and prescription. Ethical considerations are also relevant when understanding the degree to which designs solve the original problem and address user needs. Findings often lead to adjustments in the design process, such as in response to engineering disasters (e.g., Ermer, 2008), or inform future designs, especially when engineering innovations are misused or not applied as intended, as documented in other cases (e.g., Leydens & Lucena, 2018; Lucena et al., 2010; Riley, 2008).

The ill-structured nature of design problems means that not all design criteria can be met simultaneously, and there is a need for compromises throughout the design process. Decisions about which trade-offs are acceptable are normative in nature (van Gorp & van de Poel, 2001), with ethical decisions being made when moral values, such as safety and sustainability, are at stake. These trade-offs can be determined in a variety of ways, three of which are listed below.

Cost–benefit analysis: alternatives are compared based on their advantages and disadvantages expressed in monetary terms. Contingent validation, an approach used to express non-economic values (e.g.,, safety) in monetary terms, can be seen as problematic because of the incommensurable nature of values (van de Poel & Royakkers, 2011). One issue is how a choice is made once analysis is carried out. For example, it may be that the option with the highest net value is chosen or that all options having an overall advantage are eligible for selection based on other ethical criteria.

Thresholds: these are commonly used in technical codes and standards defining the minimum level of a design criterion that should be met.

Multi-criteria analysis: involves scoring and comparing options based on specific criteria. It assumes various design criteria can be measured using the same scale and that an ethical decision can be made based on relative weightings.

Although these methods introduce a somewhat systematic approach, what happens in reality can be different. Such trade-offs involve numerous stakeholders with varying opinions about what constitutes an acceptable one (van de Poel & Royakkers, 2011), and design is typically considered to be a social process, as discussed next.

Design as a social process: exploring individual and co-design dynamics

Engineers navigate a space consisting of "conflicting goals … non-engineering success standards, non-engineering constraints, unanticipated problems, distributed knowledge, and collaborative activity systems" (Jonassen et al., 2006, p. 139). Van Gorp (2005) argues that design should be considered a social process, saying that "choices are made in, and by groups of people. During the design process, communication, negotiation, argumentation, (mis)trust between engineers and power differences between engineers influence the design" (p. 29). These social arrangements for making decisions in a design process are referred to as social ethics, and project management structures may ensure the correct processes are in place for ensuring that moral values such as safety remain paramount.

As the social nature of design suggests, it is difficult to discern the responsibilities of an individual engineer. Chilvers and Bell (2018) assert that increasing focus on normative goals "focuses attention on the agency of engineers within sociotechnical networks where these same networks can both enhance and constrain engineers' capacities to contribute to positive change" (p. 205). However, Devon and van de Poel (2004) suggest ways to improve the design process, highlighting three example issues that may be considered from a societal ethics perspective. First, the division of design tasks and allocation of roles and responsibilities have implications for the distribution of responsibility. Second, how decision-making takes place and what opportunities exist to revise decisions can influence the likelihood of ethical choices. Finally, the degree to which various stakeholders, including those affected by the product, are included (or excluded) from the design process can affect the decisions made.

In many ways, the ethical decision-making process parallels the engineering design process. This comparison was supported by Bero and Kuhlman (2010); they drew parallels between the general engineering design process defined by Dominick et al. (2001) and the ethical decision-making process defined by Martin and Schinzinger (1996); see Table 12.1.

One of the key stakeholders in the design process is the user, whose needs, preferences, and experiences must be carefully considered to create products and systems that effectively meet their requirements and expectations.

Understanding users through design

Engineering designers need to consider not only how their design presents a solution to a consumer problem but also what aspects of the design may cause concerns for customers. For this reason, the approaches and tools used by designers have changed dramatically over the last three decades: engineering designers now focus on user needs in each phase of the process to create highly usable, accessible, and valuable products. These different design approaches have evolved in response to the changing landscape of technology, societal values, and the recognition of the pivotal role of users in the design process. They have unique historical roots and disciplinary applications, allowing designers to select the most appropriate approach depending on the specific context and objectives of design projects.

User-centered design

User-centered design (UCD), sometimes referred to as human–computer interaction (HCI), traces its roots back to the mid-twentieth century when the field of computer science recognized the need to accommodate human capabilities and limitations. Pioneers like Don Norman and Jakob Nielsen

Table 12.1 Comparison of the stages of engineering design and ethical decision-making (adapted from Bero and Kuhlman, 2010)

Step	*Engineering design process*	*Ethical decision-making process*
1	Problem identification	Identification of moral factors relevant to the case
2	Definition of the constraints	Identification of conflicting moral factors and definition of dilemmas
3	Ideation	Ranking of moral theories
4	Initial design of potential design solutions	Generation of various options for action and potential consequences of each action
5	Design selection and detailed design	Making the decision
6	Implementation of final design	Enacting the decision

significantly influenced the development of UCD. In this approach, engineering designers focus on the user's inherent way of doing things. According to the literature, UCD focuses on four main activity phases (Harte et al., 2017):

1. Specify the user and the context of use.
2. Specify the user requirements.
3. Produce design solutions.
4. Evaluate designs against requirements.

UCD emphasizes iterative design, incorporating user feedback throughout. It is often applied in software development and digital interfaces, where user experience is critical – as applied in engineering, UCD tends to focus on developing products and related experiences that are functional, valuable, useful, and usable.

Human-centered design

Human-centered design (HCD) shares historical origins with UCD but has a broader application, encompassing a variety of design domains. It acknowledges that human interactions extend beyond the digital realm. HCD has evolved to include architectural design, industrial design, and other fields. Sometimes referred to as participatory design, this approach focuses on incorporating users' thinking, behavior, and emotions into design to better understand their needs. It is often associated with engineering disciplines related to social impact, including biomedical engineering (e.g., prosthesis design) and biochemical engineering (e.g., manufacture of vaccines). HCD incorporates the steps used in UCD in addition to considering ways to connect with the customer:

- Understanding the end-user
- More clearly defining the problem
- Brainstorming potential solutions
- Creating prototypes
- Testing and refining with a particular focus on minimizing risk and maximizing safety

HCD is characterized by its holistic approach, considering both the user and the broader human context, including cultural and societal factors. It finds application in diverse industries, from product design to urban planning.

Empathic design

Empathic design, also known as empathetic design, was introduced by industrial designer Roger Martin in the 1980s. It emerged as a response to the limitations of traditional, functionalist design approaches.

Design practitioners (Koskinen et al., 2003; Mattelmäki & Battarbee, 2002; Suri, 2003) argue that empathy is a human quality that designers need to develop and enhance to meet customer needs by creating products that are useful and practical yet meaningful. Battarbee et al. (2002) suggest that for designers to empathize with the users, they should extend their perspectives by putting themselves in the users' shoes. Koskinen et al. (2003) and Fulton Suri (2003) argue that being an empathic designer involves engaging in specific activities to imagine being in the users' position.

Empathic design is often employed where emotional connections with the user are paramount, such as healthcare or product design. Considering that empathy – as described by the psychological literature – includes both affective and cognitive components, Kouprie and Visser (2009, p. 445) propose an empathic design framework comprised of four phases that can help designers develop and apply techniques and tools in design:

1. *Discovery* – Entering the user's world; achieving willingness.
2. *Immersion* – Wandering around in the user's world; taking the user's point of reference.
3. *Connection* – Resonating with the user; achieving emotional resonance and finding meaning.
4. *Detachment* – Leaving the user's world; designing with a user perspective.

Value-sensitive design

Value-sensitive design (VSD) emerged in the early twenty-first century as a response to the growing importance of ethics and societal values in technology and product development. This approach considers the relevant ethical values in a systematic manner (Friedman et al., 2006). It involves both consideration of evidence regarding the experiences and values of those affected by designs, making trade-offs among these values, and technical investigations analyzing designs to determine the extent to which they meet morally relevant values.

VSD is inherently ethical, aiming to ensure that design choices align with fundamental human values. It has found prominence in domains such as information technology and artificial intelligence, where ethical considerations are critical to ensuring that technology aligns with societal values. For example, during VSD, empirical investigations can be conducted to determine the role various values play in influencing behavior, and technical investigations to determine the degree to which technology supports or discourages specific values.

While all these theoretical frameworks and types of design provide valuable insights into how design is conducted, it is equally important to explore how these approaches, including ethical considerations, are effectively taught and integrated into design education to empower the next generation of designers. For more on VSD teaching methods, see Chapter 22.

Ethics of design in engineering education

In the context of engineering education, the act of design takes on a profound ethical dimension. Designing is inherently transformative, with each change to the environment raising questions of responsibility, values, and consequences. As designers engage in this process, they alter not only their surroundings but also their own ethical awareness. This ethical interplay is underpinned by the concept of situatedness, closely linked to the work of John Dewey, and constructive memory (Newman & Holzman, 1997). These ideas form the ethical foundation upon which engineering students ground their knowledge within the dynamic situations they construct during their design interactions.

Situatedness and constructive memory thus provide the conceptual bases for grounding the knowledge of designers in the situation being constructed by their interactions with the environment (Greeno et al., 1996). Situated theories have purposefully been used to understand learning as context-specific social processes by characterizing cognition as being socially shared (Clancey, 2012; Newman & Holzman, 1997). These ideas are rooted in John Dewey's early objections to stimulus-response theory (Newman & Holzman, 1997). For more on situatedness, see Chapter 11.

Within the landscape of engineering education, it is crucial to acknowledge a significant dissonance. Fry (2009) astutely notes that design ethics is "massively underdeveloped and even in its crudest forms remains marginal in design education" (p. 34). The predominant focus within engineering ethics education has traditionally centered on individual ethical considerations and applying normative ethical theories. This approach, however, falls short of addressing the intricate web of social ethics inherent in the design process, which relies on social relations and communal decision-making structures (Devon & van de Poel, 2004). In response to this disparity, advocates for a more holistic approach to design ethics, such as Kirkman et al. (2017), propose a paradigm shift. They advocate for design ethics courses that immerse students in complex problem situations, equipping them with tools and guidance to navigate and make sense of scenarios. Kirkman et al. see these tools as the "very idea of an ethical value, along with schemas and appropriate vocabulary for framing and reframing problem situations, developing options, and sorting and connecting ethical values implicated in those options" (p. 3). Such approaches bridge the gap between engineering education and the encompassing reality of ethical considerations in practice, preparing students to tackle the intricate, multi-dimensional challenges they will face.

Educational models

Several efforts have focused on incorporating existing design frameworks in the classroom. Below we provide some educational models, including curricula and program reform related to ethics of design in engineering education.

Design for sustainability – Product Realization for Global Opportunities is a hybrid course offered to students in the United States and Brazil to initiate collaboration on projects focusing on designing products that could improve housing, living conditions, and personal security. Undergraduate engineering and business students applied sustainability framework in designing new technologies (Mehalik et al., 2008).

Eco-design – Delft University of Technology (TU Delft) offers six bachelor's and master's-level courses focused on eco-design (Boks & Diehl, 2006). The leadership at TU Delft modified existing courses to include corporate social responsibility (CSR) principles, further emphasizing the importance of including a holistic sustainability perspective.

Empathic design – Empathic techniques have been integrated into capstone design (Guanes et al., 2021) and product design distance-learning courses for geographically distributed master's-level engineering students (Bairaktarova et al., 2016) to provide immersive design experience in ill-structured problems and design decision making. Other scholars have used a more formal method – the Empathic Experience Design (EED) Method (Genco et al., 2011; Johnson et al., 2014) – during the conceptual design phase of the design process with senior-level students.

Design for development – Nieusma and Riley (2010) showcased several universities in Sri Lanka and Nicaragua partnering with US universities that apply specific development interventions considering engineering as a professional activity with social justice goals.

Human-centered design – Engineering Projects in Community Service (EPICS), founded at Purdue University in the late 1990s, is a service-learning design program where multidisciplinary teams of undergraduate students partner with community organizations at local and global levels to address human, community, and environmental needs.

Both HCD and service-learning programs have been considered as "rich sites for exploring engineering students' ethical decision-making" (Corple et al., 2020, p. 264). In their work on understanding ethical decision-making in engineering design, Corple and colleagues applied the four principles of Beever and Brightman's (2016) framework of reflexive principlism: beneficence, providing benefits to society; non-maleficence, avoiding causing harm; autonomy, respecting the agency of individuals in decision-making; and justice, distributing risks, benefits, and costs equitably among all individuals. In so doing, they examined students' descriptions of (a) engineering design decision-making to determine (b) where the principles emerged and (c) how they shaped students' sense-making regarding beneficence, or what is good, throughout the design process. Corple et al. found that students demonstrated more ethical sensitivity when working closely with project partners and users throughout the engineering design process, particularly during the last phase when they delivered their product to partners and users and were required to question if their decisions were ethical. In comparison, students distanced from project partners did not incorporate user/partner needs and concerns into their engineering design decisions intentionally or consistently. However, Corple et al. (2020) highlighted that a strong emphasis on users might lead to students over-associating ethical concerns with user concerns at the cost of considerations for secondary stakeholders or environmental impacts – something they describe as outsourcing ethical decision-making to users and project partners and not considering the breadth of potential ethical implications of decisions. They conclude by suggesting that educators use 'reflexive principlism' to identify and display students' intuitive ethical decision-making during engineering design, enabling them to help students apply ethical frameworks in prescriptive ways. Corple et al. (2020) offer the following suggestions to educators:

1. Have students write down how they navigated ethically challenging engineering design decisions and what their decision-making processes were and why.
2. Use Beever and Brightman's (2016) text to teach students the four principles of reflexive principlism and describe how they may materialize in engineering contexts.
3. Ask students to examine their written decision-making processes to identify if and where the moral principles appear in their thinking.

According to Bowers (1998), although the ethics of technology is often included in specialized courses in Science and Technology Studies (STS), this topic is generally not found in general engineering courses. Dyrud (2017) suggests introducing cases that focus on artifacts developed by engineers – for example, illustrating the non-neutrality of technology using the example of the IBM tabulator that read punch cards that stored detailed information about Jews in Nazi Germany. Concerning the inclusion of CSR in the design curriculum, researchers suggest that CSR directly influences the ethical behavior of engineers (Hutchins & Sutherland, 2008).

Insights from Science and Technology Studies

As demonstrated throughout this chapter, particularly in the section on design as a social process, engineering design involves the decisions of individuals within groups. Such ideas are linked strongly to those from STS and the philosophy of technology. According to Manzini and Cullers (1992), design ethics within engineering and technology focuses on choices about the side effects and risks posed by modern technology as opposed to everyday design decisions and practice. Similarly,Verbeek (2011b) reminds us that the products of engineering and technological design mediate actions and experiences of users, irrespective of the degree to which designers engage in ethical reflection.

Technological mediation (Ihde, 1990; Latour, 1992; Verbeek & Crease, 2005) concerns how technological artifacts (co)shape human perception and behavior. It can influence moral decisions (Ihde, 1991) and "can have systematic tendencies to promote values of tendencies to promote or benefit values, such as privacy and sustainability, as well as harm or detract from them" (Brey, 2022, p. 408). Firstly, mediation of perception involves influencing people's sensory experience of reality, for example, looking through a virtual reality (VR) headset. Such technology changes what is considered 'real' and, therefore, what contributes to ethical decision-making. For example, ultrasound has allowed us to make decisions about unborn children (Verbeek, 2011a). Secondly, mediation of action is based on the idea that designs are inscribed with scripts (Akrich, 1992; Latour, 1992, 1994) that shape human action. For example, it can be considered that the microwave encourages us to eat quickly and alone. Verbeek (2011b), thus, refers to designing as "materializing morality" (p. 90), proposing two ways designers can incorporate the mediating role of technology into the design process. First, they may assess and reflect upon the degree to which actions resulting from technological mediation are morally justified. Second, they may choose to explicitly design desirable forms of technological mediation (e.g., a speed bump encourages drivers to slow down) – something which Achterhuis (1995, 1998) refers to as the moralization of technology, and which has been criticized for risking human freedom and democracy. At this point, designers may consider which values and norms are to be embodied and the ways in which these may be materialized. Verbeek (2011b) compares this process to the conceptual investigations conducted in VSD, analyzing the values supported by a design (Friedmann et al., 2006). Similarly, Vallor (2016) takes a 'technomoral' virtue ethics approach, claiming that technology can promote virtues (e.g., honesty and empathy) and vices (e.g., dishonesty, carelessness). Drawing upon the work of Fletcher (2012), Brey (2022) highlights the need to differentiate between a design which is prudentially good, meaning good or bad for something, for example "goodness for persons and goodness for society" (p. 404), from that which is morally good. For example, taking someone's money may be prudentially good for a person or an organization, but it would be morally wrong to accept it if not given with free will.

However, the mediating role of design depends not only on decisions made by designers but also on users and the unforeseen ways in which design mediates actions. Verbeek (2011b) warns of what Tenner (1996) refers to as a rebound effect, whereby technology is used in a way different from that intended, is not used at all, or when there is a difference between designer and user expectations. Thus, engineers must actively imagine how their designs might be used and expand the design process to consider a broader range of actors, values, and interests. Verbeek (2011a, 2011b) refers to Jelsma's (2006) approach to redesign, which involves analyzing user logic (how users interpret and adapt the design), script logic (how the design influences behavior), and the impact of these factors on determining design outcomes.

Verbeek (2011b) suggests a design process that allows for responsible, intentional intervention. He proposes anticipating technological mediation, which he suggests can be done using imagination – following the Constructive Technology Assessment (CTA), a systematic method that generates variations of designs based on feedback from stakeholders and thus focuses on how technology emerges from a specific context – and using scenarios and simulations focusing on using a design in specific situations in various ways. While processes like CTA are considered a means for the democratization of design, thus removing the fear of unknown technology, they are limited in that little attention is paid to non-human actors.

Anticipating technological mediation will result in further complexities, trade-offs, and questions, for example, the degree to which potential mediation is justified. Including a desirable mediating characteristic can negatively affect other design features. To illustrate, Verbeek (2011a) describes automatic speed restrictions in cars that come at the cost of freedom and experience. Assessment of mediation involves stakeholder analysis that considers moral arguments associated with designs, including reflecting on, for example, the morals of intended and implicit mediations, the form of mediation (e.g., forcing action versus nudging), and the outcome of mediation in society (Verbeek 2011b). In discussing mediation assessment, Verbeek (2011b) considers the issues of responsibility, freedom, and democracy – initially questioning the extent to which humans can be held responsible for actions mediated by technology. He distinguishes between causal and moral responsibility, proposing that technology (co)shapes moral responsibility by mediating human action and contributing to causal responsibility. Thus, responsibility is shared between humans and technology, with the designer taking some responsibility for design decisions. Such factors become increasingly important when considering technology such as autonomous vehicles. Similarly, in his discussion of freedom, he draws upon the work of Foucault (1988), who argues that freedom results from the situated nature of human life, meaning it cannot exist in an absolute sense. Many forms of mediation do not force specific actions; instead, they inform them (e.g., through persuasion), meaning technology is then considered a coauthor of what we do. Foucault thus argues that technological mediations are limited and questions whether we should allow technology that allows no room for freedom of individuals (e.g., by oppressing or limiting human behavior). The value placed on individual freedom links directly to the way in which technology can be perceived as a threat to democracy, with Verbeek (2011b) suggesting that democratic processes such as CTA be used to encourage democratization of the design process. Technology can also be used to promote democratic values, for example, the 'good life.'

Concluding remarks

In this chapter, we discussed engineering design foundations through the lens of ethics, providing a synopsis of emerging issues in ethics in engineering design education. We presented the development of engineering design thinking in problem-solving, particularly related to engineering ethics, to demonstrate that engineering design is as much about the process as it is about providing a service or product intended for human use. Designers nowadays focus on the user and their needs in each phase of the design process to create highly usable, accessible, and valuable products. Regardless, there is a fundamental tension rooted in the structure of society (Conlon & Zandvoort, 2011), which still results in a lack of interaction with the externalist approach that engineering ethics takes to technology, as well as a focus on products as opposed to processes (van de Poel & Verbeek, 2006).

In the last several decades, we witnessed that the more advanced technology becomes, the more humanity is exposed to unanticipated side effects and risks of harnessing technology (Wolin, 2001). Many scholars echo calls from Conlon and Zandvoort (2011) to examine the different resources available to engineers to help them have a voice in public policy, including consideration for the values and beliefs of professional engineering bodies and individual engineers. Given the impact of engineering design in society, engineering educators have an instrumental role in emphasizing the importance of ethics in the engineering profession, including design, and in continuing to integrate ethics as a core competency in the engineering curriculum.

Engineering design education should incorporate a robust ethical component throughout the curriculum. It should encompass ethical principles and considerations relevant to design, encouraging students to recognize and address the ethical dimensions of their work. It can incorporate real-world problem scenarios by emphasizing complex, real-life problems in design education. These scenarios should expose students to multifaceted challenges, integrating technical, social, and ethical dimensions, mirroring the intricacies of professional engineering practice.

Further, fostering interdisciplinary learning and collaboration and encouraging students to work with experts from diverse fields – including ethics, sociology, and policy – can provide a more holistic, comprehensive, and socially responsible approach. Educators could shift the focus of engineering ethics education from individual ethics and normative theories towards social ethics methods (see, e.g., Chapter 3), encouraging students to explore social relations and decision-making processes that underpin design, aligning more closely with the iterative nature of design. They can encourage students to continually question assumptions, assess consequences, and engage in reflective dialogues about the ethical implications of design.

Engineering educators could consider empowering engineering students to advocate for public policy (see Chapter 6) that aligns with ethical and societal values; engineering design education must continually adapt to evolving technological and societal landscapes, and flexibility and adaptability should be core principles to keep curricula relevant. Professional engineering bodies should play an active role in promoting and supporting ethics education. They should provide resources, guidelines, and forums for discussing ethical challenges in engineering design.

By implementing recommendations and recognizing the implications, engineering design education can better prepare students to navigate complex ethical dimensions of the field, fostering socially responsible, thoughtful engineers well-equipped to address the challenges of our ever-evolving technological world.

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