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A POST-NORMAL ENVIRONMENT-CENTERED APPROACH TO ENGINEERING ETHICS EDUCATION

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Introduction

What do we mean when we use the term 'ethics' when discussing engineering? Being 'ethical' implies applying well-reasoned values and morals, and today, concepts like sustainability, equity, and diversity are increasingly associated with ethics in engineering as well (Committee on Education, 2019). Ethics extends beyond professional codes that specify what one must do as part of the engineering profession to include what one should do as a responsible and moral person (Chance et al., 2021). Developing the ability of engineers to apply ethical judgment when facing ethical dilemmas necessitates providing future engineers with education in ethics to support their moral development (see Chapter 10) and reflective practice (see Chapter 25). Engineers often associate the term 'ethics' with workplace health and safety, but today's complex environmental challenges imply embracing a broader view of health and safety to encompass the well-being of our planet and all its constituents, living and nonliving. The term 'global responsibility' is promoted by the United Nations (UN) to capture this expansive understanding of ethics. This chapter discusses how to foster global responsibility among engineers (including future engineers) and shift how they think and behave collectively and as individuals. Definitions (as fuzzy as some of them may be) are necessary for facilitating dialogue, and this chapter seeks to identify and define key terms relevant to moving forward the dialogue on what constitutes ethical engineering and how to achieve it.

In 1828, Thomas Tredgold characterized civil engineering as "the art of directing the great sources of power in nature for the use and convenience of man" (Alder, 2022, p. 2). This perspective asserts that engineers serve society by harnessing natural resources, and it undergirds many engineering sectors even today. Even in contemporary times, environmental engineering is often viewed as "improving ecological conditions," mainly to make surroundings "more suitable for humans to live" (Joshi, 2021, ¶3). However, modern leaders, like those at the United Kingdom's Institution of Civil Engineers (ICE), acknowledge "the detrimental effect that the industrial scale development which started with the Industrial Revolution [has] on our planet" (Alder, ¶3). We argue that although our early ancestors had to live with the pace of nature and struggle to circumvent its vagaries, humans today 'engineer' the natural environment to an unhealthy and unsustain-

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able extreme. We question humans' attempts to control nature, particularly through engineering. We argue that the balance between serving humans and respecting other species, ecosystems, habitats, and so on constitutes an ethical dilemma that must be addressed.

Humans and the engineers serving them have extracted, exploited, rerouted, canalized, and otherwise 'modified' nature, ring-fencing the most dramatic features into encapsulated parks and 'natural reserves' but covering much of the rest with asphalt, concrete, brownfields, and contaminated wastelands. Now, confronted with urban heat islands, extreme weather, pollution, resource shortages, loss of biodiversity, and climate change, some propose 'extreme engineering' that is highly ambitious and employs unconventional engineering practices to address complex and severe challenges. 'Extreme engineering' practices are characterized by their aggressive groundbreaking approaches, high technological innovation, and high potential for impact and risk. Yes, the urgency to realign our relationship with nature is more pronounced than ever. Still, these extreme engineering methods are subject to growing criticism based on ethics and the risks of implementing such large-scale interventions. *How might we better respond? How can engineers achieve 'global responsibility' to people and the planet, including the non-human?*

What we need to move away from is the extractive cradle-to-grave capitalist model for producing and monetizing engineered products at the expense of the planet, including the environment, other people, and the non-human. The 'Anthropocene' is frequently invoked when questioning the prevailing extractive and human-first mindset. The National Geographic Society (2023) defines the Anthropocene as a distinct epoch "during which human activities have impacted the environment enough to constitute a distinct geological change" (¶3), exerting an overwhelming influence on the Earth's climate, geology, and ecosystems.

In this conceptual chapter, we use reflexivity – the quality of a dialogical approach to tackling complex societal problems – to assess existing normative practices and propose a framework for moving beyond them. We do this in response to the current ecological crisis; we call on engineers to help define and forward a paradigm shift (Kuhn, 1962) to transition from extractive practices and mindsets to more humble, healthy, and sustainable ones. Overall, we use three lenses: (1) reflexivity, (2) post-normal science (PNS) underpinning post-normal engineering (PNE), and (3) environmentalism.

We draw inspiration from the global conversation questioning the current status quo and calling for new and different responses, particularly the call for 'post-normal science' (Funtowicz & Ravetz, 1993). The conversation calls for a shift from the 'normal' way of doing things to a more refined 'post-normal' way of thinking and being – a concept we find helpful for repositioning engineering. Historically, societies and their groups of practitioners and thinkers (like architects and philosophers) have periodically transitioned away from paradigms once the mindset has become the status quo or normative enough to be named (e.g., modernism and structuralism, discussed by architects and philosophers alike). Critics from various groups reacted to and pushed against the boundaries of their time's existing normative ways, the status quo, to set forth via new paradigms (e.g., post-modernism and post-structuralism, respectively). They accomplished this using reflective thinking, dialogue, and rigorous debate. We experience the results of paradigm shifts when we observe paintings and sculptures, dwell in architecture, or read literature, poetry, and philosophy that integrate and seek to manifest the new mindset. Post-modernism and post-structuralism have been expressed in all these realms, and this chapter calls for engineers to embrace the emerging new post-normal paradigm and express it in their work.

We explore the idea that engineering requires a more evolved post-normal perspective regarding its role and potential. The solution isn't merely about improved models, technologies, or algorithms; it involves a collective view of engineering as an endeavor to address urgent political issues rooted in ethical and holistic thinking, transdisciplinarity, global accountability, and public participation. We contend that engineering can fully realize this aspiration only after its educational foundation is reshaped using these values. If the goal is to engineer responsible solutions to societal challenges, then policy must foster this enhanced form of education within the engineering community.

Ecological crises are exemplary for enacting post-normal approaches (such as PNS and PNE). These approaches are also relevant for addressing other crises, such as pandemics and inequality. Thus, the relationship between PNS/PNE and the environment is that the environment, with its different crises (e.g., the climate crisis or the biodiversity crisis), is used to explore aspects of PNS/PNE and the ethical frameworks that inform these practices.

This chapter aims to help bridge two realms (ethics and environmentalism), drawing from environment-centered ethical frameworks, to foster a new way of thinking about engineering. We discuss typical engineering values and practices and question what 'responsible engineering' means today. We propose a response called 'post-normal engineering' and reflect upon a range of existing normative theories, identifying some pros and cons of each approach and then proposing how engineers, engineering teachers, and future engineers might respond in a more effective post-normal way.

Positionality

The unique perspectives of each author on our team have steered the direction and scope of this chapter. We all have a foundation in design and engineering, specifically focusing on the built environment. Tom teaches technology ethics, technology assessment, public/user engagement in science, technology, engineering, and mathematics (STEM), and techno-anthropology within a department of sustainability and planning. His research emphasizes the integration of ethical judgment and participatory methods in STEM practices and education. Shannon teaches students architecture, engineering, and educational planning, emphasizing ecological principles. She advocates using site-specific, culture-specific methodologies. Gaston, a researcher in moral philosophy and science and technology studies (STS), is a philosophical activist and founder of the New Humanism Project. Our mutual interest in PNS and the desire to adopt more transformative approaches to tackle global challenges brought us together as co-authors and inspired this chapter's creation.

A post-normal approach for engineering

As we aim to propose the concept of reflexivity to rethink the 'normal' practice of engineering and its education system away from destructive and extractive practices, we believe that PNS provides inspiration and clues for how to do this. In 1993, Funtowicz and Ravetz introduced the concept of PNS as an evolved form of expertise, mainly designed for advising policy-makers during times when "facts are uncertain, values in dispute, stakes high and decisions urgent" (Funtowicz & Ravetz, 1993, p. 10). This vision now aligns with the ongoing transformation in how technoscience and engineering are perceived. Central to these evolving approaches is the realization that experts grapple with numerous uncertainties and value-laden viewpoints when shaping policies on intricate sociotechnical and ecological matters. These experts are under constant pressure from the political, public, and economic sectors to provide solutions that span multiple areas – for example, climate change, the COVID-19 response, large dam constructions, and genetically modified organism (GMO) policy-making. Consequently, engineering perspectives are transitioning. There's a growing understanding that the Anthropocene's multifaceted challenges can't be addressed with the same mindset that initially led to them; mechanizing solutions for every emerging issue isn't viable.

When introducing the idea of post-normality in 1993, Funtowicz and Ravetz (1993) identified four problem-solving strategies: core science, applied science, professional consultancy, and post-normal science. Each of these four types of scholarly activity has its equivalent in engineering. Core science in various domains is the foundation of engineering. Applied science and professional consultancy are well-described engineering practices. Traditional engineering, typified by its reliance on applied science and problem-solving, addresses routine challenges using established methods. However, these standard solutions and tools fall short regarding more intricate and unpredictable issues.

In the original writings on PNS, engineering was identified as applied science and professional consultancy. Engineering implies 'applied science' in the sense that it applies (natural) scientific theories and laws under controlled circumstances in developing new technological artifacts that can be used to make life easier for its target groups. Biotechnology and software engineering are examples of this type of engineering. Engineering can also involve 'problem-solving' where engineers address societal problems. Examples are engineering infrastructure projects (e.g., introducing central heating in major cities or constructing railway systems to connect a country or countries). This form of engineering also requires control over the context in which infrastructure is set.

Jerry Ravetz (2006) and Tom Børsen (2015) have linked PNS to technological risks and explored how the PNS framework can be applied to understanding, assessing, and managing the risks associated with technology. They argue that a broader, more inclusive approach is needed for complex and high-stakes technological issues than the approach provided within traditional scientific methodologies. Fanny Verrax (2017) also referenced PNE in a paper in *Futures*, calling experts to rethink the 'normal' engineering identity. We follow this route in part as we are concerned with how engineering can address urgent policy issues related to the environment where facts are uncertain, stakes are high, and values are in dispute. We do not perceive 'engineering' as only an applied science and client-serving consultancy (i.e., engineering must serve a good greater than the funder's request). PNE is engineering that effectively responds to post-normal times (Sardar, 2010). PNE is not (yet) defined; thus, it is one of the quests of this chapter to describe this.

At this point, we want to emphasize that other traditional and PNE practices hold value and will remain relevant. Yet, we argue that more is needed to address the current climate and environmental crises than relying solely on applied science or conventional problem-solving methodologies. Although we see immense value in the engineering professions, we also ask how engineers, as individuals and as members of professional collectives/organizations, can better tackle significant environmental challenges.

PNS develops and presents science-based advice to policy- and other decision-makers when trying to address crises through policy measures. Post-normal science-based advice portrays uncertainties at different levels – empirical, methodological, theoretical, institutional, legal, ethical, and so on (Benessia & De Marchi, 2017) – and manages conflicting stakes and ethical dilemmas through establishing extended peer communities (Meisch et al., 2022), honest brokery (Pielke Jr, 2007), and quantitative storytelling (Saltelli & Giampietro, 2017). PNE differs from PNS as PNE practitioners do not (only) provide advice; they address post-normal crises by developing sociotechnical solutions and strategies.

The ethical landscape of post-normal engineering in the Anthropocene

Delving into the 'ethical landscape' of PNE, we are inspired by a critical perspective on our current coexistence in the Anthropocene. Paul Crutzen, an atmospheric chemist, was the first to coin the term 'the Anthropocene' to describe the epoch where human actions are the dominant force impacting Earth's geology, climate, and ecosystems. Yet, the foundational beliefs and values of PNE differ from the conceptual notions associated with the Anthropocene. Crutzen (2006) proposed technical solutions, specifically geoengineering methods such as releasing sulfur compounds into the atmosphere to mitigate the sun's heat. In our view, such a proposal doesn't resonate with the post-normal emphasis on humility. It seems to overlook the potential unexpected consequences of such interventions. For instance, geoengineering might be a plausible reply if society runs out of options. However, implementing such a grand plan will require pervasive reflection, enormous assessment of unexpected consequences, and extensive discussion regarding which ethical frameworks are appropriate to consult before action can be taken. We advocate referencing PNE when discussing pressing contemporary issues like climate change. These challenges require a collaborative approach among diverse stakeholders, emphasizing humility and accountability. Addressing the intricacies of problem-solving in the Anthropocene harmonizes with the call from Jonas (1984) to prioritize the sustainability of future conditions. Jonas argued that potential negative outcomes should be given more weight than positive projections in ethical considerations.

The literature on PNS and STS provides concepts and tools to manage uncertainty, for example, the Numeral, Unit, Spread, Assessment, and Pedigree (NUSAP) approach to uncertainty (Funtowicz & Ravetz, 1990; van der Sluijs et al., 2005) and stakeholder controversies (e.g., Social Construction of Technology (SCOT)). Regarding the 'ethical values in dispute' part of the PNS one-liner (coined by Funtowicz and Ravetz and frequently repeated), 'when facts are uncertain, stakes high, values in dispute, and decisions urgent,' the literature provides little to go on, although a forthcoming special issue of *Futures* promises an investigation of relationships between 'Post-normal Science and Ethics' (Børsen & Meskens, under review).

Although we cannot and should not completely abandon the anthropocene perspective, we believe that responsible engineering originates from a deep understanding of our global challenges and an acute awareness of their ethical ramifications. This shapes how we deliberate and execute solutions to benefit present and future generations, human and non-human. The following sections identify a broad palette of ethical theories that engineers can choose from and combine when engaging with urgent political issues. We argue that there is not one ethical framework that engineers can apply in isolation to post-normal problem-solving. The engineer must reflect and discuss with self and others what ethical frameworks fit for individual (yet often complex and overlapping) issues.

Helpful ethical frameworks are covered in detail elsewhere in this handbook (e.g., virtue ethics, deontology, utilitarianism, and the common good; see Chapter 2) and continue to be relevant in PNE. Other ethical frameworks, such as the Golden Rule (do unto others as you would have them do unto you) and the Fairness approach defined by Rawls (1971), are relevant in PNE. The Fairness approach posits that a just society is one where principles are selected impartially and without bias, following two primary tenets: *basic liberties for all* and *the difference principle*, which permits inequitable responses only if they benefit the least advantaged members.

Foundational ethical perspectives like deep ecology, sustainability, and land ethics (described later in this chapter) recognize environmental systems' intricate and interconnected nature, emphasizing the importance of considering the broader ecological community in our actions and decisions. No engineering solution can fully encompass every facet of this intricate context. Invariably, certain elements will remain external to the system addressed by any solution proposed. The environment's components are intertwined, forming a holistic web where interventions in one segment inevitably impact others. Including environmental ethical frameworks in the palette of ethical frameworks for PNE is extremely important, so we describe them here. We note that Chapters 11 and 15 also provide helpful guidance for readers interested in environmental topics.

Some professions favor specific frameworks over others, but their preferred approaches may only address some of the profession's dilemmas. Engineers, policy-makers, and practitioners in many fields must learn a wider array of ethical approaches and learn when to integrate them based on the given contexts; given today's post-normal complexity, they cannot rely solely on the rules of thumb favored in their professions.

For us, PNE is characterized by a higher degree of complexity than other forms or strategies of problem-solving. PNE is embedded in a more contradictory field of interests and stakeholders than other forms of problem-solving. We are in a post-normal context where policy-makers cannot look towards normal engineering to provide adequate response.

Reflexivity

Reflexivity is a vital ethical virtue for engineers in this complex age. Traditional ways of thinking and working are evolving, and with this evolution comes a need for engineers to be deeply introspective and outwardly attuned, based on an awareness of the context in which they operate and of the values and beliefs that drive them to do what they do. We propose to understand reflexivity as this kind of awareness. If we imagine the complexity of an environmental problem as making an ethical appeal to us to deal with it 'fairly,' then we can understand reflexivity – in response to that appeal – as an *ethical attitude*, being critically aware of our own position, interests, hopes, hypotheses, beliefs, and concerns (Meskens, 2017). Chapter 25 discusses possible approaches to teaching and practicing reflexivity. It suggests that dialogue with yourself and others is the basis of reflexivity and that the dialogue should ask critical questions like: *What is the problem we face? In what way(s) is it complex? Should we do, or have done, something else? What might we be overlooking? How could we improve?* Chapters 35 and 36 ask these types of critical questions regarding the role of ethics in engineering accreditation. Chapter 31 critically probes assessment practices, confronting assumptions and biases about behavior and culture.

Important to understand is that reflexivity as an ethical attitude emerges in dialogue with others, a dialogue that – by its very form and method – is emancipatory and (respectfully) confrontational simultaneously (Meskens, 2017). It connects engineers with different views and meaningful ethical frameworks and nourishes their competence. From this perspective, we can also understand why and how reflexivity grounds other values, like precaution, transparency, accountability, protection and empowerment of the weak, and even sustainability. This kind of dialogue would stimulate sensitivity to these ethical values among all concerned and consequently enable meaningful interpretation. In this sense, it would also become an 'authoritative place' where these values could be applied as principles to inspire and steer (engineering) policy (Meskens, 2018). Dialogue with others should always involve parallel individual contemplation (this idea has religious underpinnings from, e.g., Saint Thomas of Aquinas). On the other hand, individual contemplation could and should inform and be informed by interaction with others.

We argue for rooting extended discussion of ethical and sustainable (a.k.a. post-normal) engineering in the community. This requires engaging with stakeholders. Public participation is necessary to ensure benefit to the more vulnerable. This begs the question of how to set up an extended peer community to reflect and act – to form a new and improved paradigm, advocate for change, and integrate its tenets in thought and deed. The question will be contemplated in a subsequent section, where we discuss tools for fostering public dialogue.

Ethical approaches – an overview

We now outline the ethical terrain of environment-focused engineering to explore the prospects of post-normal thinking. Engaging with classical anthropocentric (human-first) theories and newer environment-centric approaches can illuminate the engineering community's diverse and sometimes clashing beliefs. Here, we highlight ethical concerns that, in our view, could guide ethical engineering practice and education – especially if we intend to conquer contemporary environmental challenges and crises. We believe it is essential to understand all the tools we currently have for enacting global responsibility and addressing today's challenges.

Therefore, we open the toolbox of prevailing ethical approaches, considering what they offer, identifying some of their shortcomings, and suggesting how they might be integrated into the new 'post-normal' paradigm for engineering. This curated set of existing environment-focused lenses can support (future and current) engineers and engineering educators in cultivating and advocating for environmentally and socially considerate practices, policies, and mindsets. Note that the concepts we highlight are all open to interpretation. They should be topics of dialogue themselves (within political, academic, policy-making, and other professional circles, including engineering) to unveil different interpretations and interests and discern the positions of various actors. First, we apply reflexivity in identifying and briefly defining *core ethical virtues* and *procedural ethical values* that will remain valuable. Here, we use terminology proposed in the publication *The Ethical Foundations of the System of Radiological Protection* from the International Commission on Radiological Protection (2018). Then, we shift the discussion toward *responsible complexity management strategies* from business and economics. We identify *other environment-centered ethical frameworks* that provide a foundation for moving engineering ethics (and) education forward. Finally, we look at some environmentally important *policy issues*, reflect upon frameworks for *fostering public dialogue*, and consider how we can put them to work with PNE.

Core ethical virtues and procedural ethical values

Moving forward will require using many widely recognized *core ethical virtues*. These include the principles of *beneficence* and *non-maleficence*, which require doing good and avoiding harm. *Prudence* (wise and judicious decision-making) and *respect for dignity* (which values intrinsic worth) will also be important concepts to bring forward. Likewise, *openness* and *tolerance* are essential concepts, so the community of reflexive thinkers/engineers will welcome varied knowledge and opinions. *Procedural ethical values* like *accountability* (owning responsibilities and outcomes), *transparency* (ensuring clarity and openness), and *inclusiveness* (valuing and supporting diverse participants, with a particular focus on those potentially affected by engineering practices) must also be retained.

Responsible complexity management strategies

Responsible complexity management strategies that can inform PNE include *global responsibility* (upholding duties beyond borders, considering local and global impacts of our decisions and our profession), *intergenerational ethics* (considering possible consequences for future generations), and *holism* (embracing the interconnectedness of all things). *Inter*- and *transdisciplinarity* can help us break silos to achieve more holistic solutions. *Action research* provides iterative approaches to learning from experience and refining practice over time based on real-world learning and application of research. Ideals of *cosmopolitanism* can help us cultivate self-critical world-citizen perspectives (Meskens, 2022).

Many frameworks have been offered to help make activities in our current economic model more environmentally and socially sustainable. These include *corporate social responsibility* (CSR), a model for self-regulating practices within businesses and organizations (including the business side of higher education) to ensure organizations are socially accountable to themselves, their stakeholders, and the public. By practicing CSR, an organization can become more conscious of its impact on society's economic, social, and environmental realms. Via CSR, companies aim to contribute positively, often by adopting sustainable practices, engaging in philanthropy and ethical labor practices, and reducing their ecological footprint. Yet, for CSR to be effective, it needs more stringent standards, greater transparency, increased integration into core business strategies, and long-term commitment to genuine change (Christensen et al., 2021). It is largely ineffective because it is voluntary, because businesses often prioritize short-term gains and shareholder returns above long-term sustainability goals, and because CSR is frequently treated as a peripheral activity rather than a core business strategy. Global supply chains are incredibly complex and challenging to regulate, and the lack of standardization in defining CSR makes it difficult to measure and compare effectiveness. Quantifying social and environmental impact is ill-defined, and it is hard to evaluate efficacy without clear metrics. Moreover, some CSR efforts only address specific areas of concern, neglecting other important aspects of social and environmental responsibility (Scherer, 2018). Unfortunately, many companies engage in 'greenwashing' where they exaggerate or falsely claim to benefit the environment, and such abuse leads to skepticism and distrust – undermining the credibility of CSR.

The *doughnut model of economics* (Raworth, 2012) presents a framework for sustainable development, aiming to support essential human needs within Earth's ecological limits. It visualizes an ideal zone (shaped like a doughnut) that avoids both deprivation and ecological overshoot.

The *circular economy* is a significant and influential approach driven by sustainable development and resource efficiency principles. It proposes an alternative to the traditional linear economy (that follows the 'take, make, dispose' or 'cradle to grave' model) and encompasses sustainability principles, resource efficiency, and waste reduction. Proponents advocate for a closed-loop system where resources are reused, repaired, refurbished, and fully recycled. The circular economy is being implemented and practiced in various industries and by policy-makers worldwide. It provides practical strategies, demonstrating how economic activities can be restructured to minimize waste and negative environmental impact while maximizing resource efficiency. The concept has been shaped by, for example, Ken Webster and the Ellen MacArthur Foundation, Walter Stahel and the Product-Life Institute, 'Cradle-to-Cradle' concepts from William McDonough and Michael Braungart, and the European Union's Circular Economy Action Plan (part of the European Green Deal).

Another vital contribution in this realm is the *blue economy*, proposed by Gunter Pauli to complement the circular economy with solutions inspired by nature and emphasizing the sustainable use of local resources.

An investigation of economic models can only be completed by looking at concepts and tools designed with engineers and designers specifically in mind. Prominent among these are the cradle-to-cradle (C2C) design principles mentioned above (McDonough & Braungart, 2002), which seek to balance economic, environmental, and social concerns. Treating waste as a resource for another cycle is central to C2C. In contrast to recycling, which can diminish quality and introduce additional pollutants, upcycling seeks to enhance an item's value. Initial designs must be crafted to support ongoing use in various new forms. Design begins with careful material selection, avoiding 'X list' materials detrimental to humans and the environment, seeking substitutes for 'gray list' items (those presently indispensable but problematic), and always giving preference to safe, sustainable materials (from McDonough and Braungart's 'P list' of positive and healthy substances). Regenerative design minimizes harm and actively feeds and enriches the local environment. C2C designs aim to revitalize ecosystems, enhance biodiversity, and champion local communities, kindling synergies between development and ecology. Although we recognize C2C as a business-oriented approach grounded in the capitalist economy, we believe it provides some valuable concepts for students, designers, and policy-makers.

Janine Benyus introduced *biomimicry*, which is related to the C2C approach. *Biomimicry* focuses on innovation inspired by natural processes and biological systems, encouraging designers and engineers to create products and solutions that emulate nature's patterns. The approach supports sustainability, encourages a symbiotic relationship between human development and the environment, and fosters a deeper appreciation of the natural world.

Reflecting on why the techniques identified above haven't worked and why companies and institutions of higher education don't already achieve sustainability using them, we cite their voluntary nature and the ongoing hold of capitalist ideals acutely evident in the business of engineering and the built environment. There's more to the story, though. There's also a pervasive detachment from nature and a sense of technicality or instrumentality that philosophers of STS call the technical frame. Changing extractive ways of thinking firmly rooted in the engineering profession is very hard. Big organizations, including academic ones, are known for high resistance to change.

Empson et al. (2019) recommend a less opt-in approach, arguing that, in post-normal times, no design activity should be considered 'creative' that is not deeply sustainable. Nevertheless, we still see praise doled out by prize-awarding organizations for projects that lack sustainability or effectively constitute greenwashing.

Ecological economics denotes an interdisciplinary research area that advocates for an equal exchange between humans and nature. This means that when humans take from nature, they must give something back. That is the foundation for economic exchange. In a 1994 paper published in *Ecological Economics*, Funtowicz and Ravetz asked about "the worth of a songbird" (Funtowicz & Ravetz, 1994, p. 197). They argued that ecological economics requires a PNS to address the dilemma of "setting a monetary value on an irreplaceable songbird [which] forces us to be clear about what is being valued, how it is done, and indeed, what value is" (p. 198). There are no certain answers to this question. Stakes are high, and ethical values are in dispute.

Other environment-centered ethical frameworks

Looking at *other environment-centered ethical frameworks*, we draw an arc from *sustainability* (aiming for longevity and balance) through *deep ecology* (recognizing non-human entities) to *land ethics* (valuing the sanctity of the land), *material ethics* (emphasizing regenerative practices), and *values embedded* within the things we create.

Sustainability

Sustainability is a core concept. In post-normal times, living in harmony with nature is a fitting response to the conventional notion of controlling nature. The United Nations General Assembly (2022) has now stated that "to achieve a just balance among the economic, social and environmental needs of present and future generations, it is necessary to promote harmony with nature" (p. 2), but this seemingly prioritizes human needs, a flaw we see. Drawing from the ancient Greek philosopher Marcus Aurelius' (2002) insights that "all things come to their fulfillment as the one universal Nature directs" (Marcus Aurelius, 2002, Book VI, statement 9), we see a nuanced relationship: nature continues to guide the definition of harmony, but it now assumes the humble and vulnerable stance traditionally ascribed to humans.

The United Nations (UN) emphasis on living harmoniously with nature has been in its documents since at least the 1980s. The 2009 UN General Assembly Resolution 64/196 references the 1980 Resolution 35/7, the *Draft World Charter for Nature*, highlighting the dependency of life on nature's continuous processes and the dangers of excessive exploitation (United Nations General Assembly, 1980). The UN doesn't suggest reverting 'back to nature.' Instead, it advocates a balance among human economic, social, and environmental needs, aligning with the definition of sustainable development provided in the Brundtland Report (World Commission on Environment and Development, 1987). Here again, human needs have been prioritized.

Practical tools to support sustainability include *carbon calculators* (Wackernaegle & Rees, 1996) and the UN *Sustainable Development Goals* (SDGs). From a critical perspective, Seniuk Cicek et al. (2023) contend that many methods, especially those appealing to engineering mindsets like the SDGs, favor the Global North. They originate in values defined by the Global North. Moreover, when organizations in wealthy countries work toward high-level goals without drilling down into specific targets – referencing just the overarching SDG titles like *quality education* (SDG 4), *gender equality* (SDG 5), *decent work and economic growth* (SDG 8), and *industry, innovation, and infrastructure* (SDG 9) – their efforts can help to raise the standard of living locally without doing anything to help the Global South. Gains in rich countries can exacerbate inequalities between rich and poor countries. In response, Ochoa-Duarte and Peña-Reyes (2020) champion the concept of *Buen Vivir*, which, as described by Seniuk Cicek et al., is "anchored in Latin American principles and emphasizes biocentrism, postcapitalism, decolonialism, and depatriarchalization" (p. 55–56), presenting it as an alternative to address disparities they see within the SDG approach. *Buen Vivir* is also discussed in several chapters of this handbook (see Chapters 1, 8, 9, and 15).

Regarding learning and teaching sustainability in subjects including engineering, the UN Educational, Scientific and Cultural Organization (UNESCO) identified eight competencies that all students need to develop. The sustainability-related competencies are systems thinking, anticipatory, normative, strategic, collaboration, critical thinking, self-awareness, and integrated problem-solving (Didham, 2018), and they resonate with our idea of fostering reflexivity through dialogue.

Deep ecology

The term *deep ecology* was coined by the Norwegian philosopher Arne Næss (1973). It is a philosophical and ethical approach to environmentalism that emphasizes the inherent worth of all beings, regardless of their utility to human needs. Næss argued that the prevailing approach to environmental problems was too shallow, focusing on pollution and resource depletion concerning their impacts on humans. In contrast, he argued for a 'deeper' approach that recognizes the fundamental interconnectedness of all life. Ethical frameworks for post-normal times need to reflect the interconnectedness of nature more holistically.

Around the same time, Ian McHarg (1999) criticized the assumed superiority of modern humans, noting that (hu)man's presumed supremacy "lies in the inheritance of tools, information and powers from his predecessors" (p. 287). McHarg proclaimed the value of 'primitive' societies, promoting ideas of pantheists and animists that "the entire world contains godlike attributes: the relations of man to this world are sacramental. … the actions of humans in nature can affect their own fate; these actions are consequential, immediate, and relevant to life. There is, in this relationship no non-nature category" (p. 287). Hunter-gathers recognized and honored seasons and maintained balance with nature; they honored and revered the prey that sustained their lives. People living this way "could promise their children the inheritance of a physical environment at least as good as had been inherited – a claim few of us can make today" (p. 288).

Consistent with this approach, *deep ecology* asserts that humans aren't superior to other life forms. Instead of conserving the environment solely for human advantage, *deep ecology* promotes biocentric equality – valuing every living entity, from microorganisms to large mammals, for its inherent right to exist and thrive. Resonating with Marcus Aurelius' views, this perspective emphasizes that humans are just one part of the broader web of life.

Land ethics

Humans have exploited Earth's land and its constituent components, plants, and animals. Capitalist systems and economic foci have exacerbated this exploitation, but Western societies' one-way approaches to land and earth also have religious roots. Religious texts seemingly grant humans the absolute right to dominate over plants, animals, and land. Probing our languished, or absent, set of *land ethics*, brings us back to McHarg's scathing critique titled *On Values*. McHarg (1999) argued that the pronouncement in Genesis of man as "exclusively divine, given dominion over all life and non-life, enjoined to subdue the earth" (p. 288) set the tone for calamity. Islam, Judaism, and Christianity all inferred from Genesis values regarding how humans should relate to nature. In the past, Islam saw humans as stewards, entrusted to "make paradise on earth, make the desert bloom" (p. 296). In contrast, Judaism and Christianity leaned towards conquest. When the "medieval Christian Church introduced otherworldliness" (p. 296), it deepened the human perception of Earth as dangerous and impure (think of the paintings by Hieronymus Bosch of worldly, carnal sins, for example). The Western world, particularly in its more modern form as the Global North, has often viewed nature as a "crude, vile, lapsed paradise" (p. 296) and sought to conquer it. Although the West has made big achievements in social equality, McHarg acknowledges, as for the land, "nothing has changed" (p. 296). An ultimate expression of this exploitation was the urban landscape of the United States, which McHarg described as "the ransacking of the world's last great cornucopia [and] the largest, most inhumane, and ugliest cities ever made by man." This he saw as a clear example of "profound ignorance, disdain, and carelessness" (p. 298). This indictment targets architects, engineers, and financiers and helps explain why the activities of well-intentioned and often 'god-fearing' people have resulted in such low levels of sustainability.

Material ethics

As we contemplate the ethics of land use and our relationship with materials like rocks, minerals, and plant-derived resources, it is clear that we have viewed them as resources for extraction and consumption without giving much thought to long-term repercussions. We must instill a new code of *material ethics* that acknowledges the limited nature of our planet's bounty. Implementing this code across architecture, engineering, and construction sectors could drive a paradigm shift. Instead of viewing materials as endless supplies, we'd understand their limited nature and the broader implications of our cradle-to-grave consumption patterns. Adopting a lifecycle perspective would prioritize regeneration and prohibit depletion.

Engineers make key decisions regarding the selection and use of materials. They have a moral obligation to consider the implications of their choices regarding extraction. A shared code of *material ethics* would require engineers to consider not just the functional properties of materials but also their environmental impacts and the social implications of their mining, processing, and disposal. Tony Fry (1999, 2009) highlighted the role of designers and technical design in today's unsustainable world and recommended a rethought design practice that finds inspiration in intercultural, interdisciplinary, and transdisciplinary creation. Fry stated that technical design is vital for human and ecological development and observed that the dominant technological frame threatens our future. It is 'defuturing.' Thus, the central move in addressing the Anthropocene is to develop a new relation to technology.

Values embedded

Pertaining to land and material ethics alike, designers must reflect on the *values embedded* in the structures and products they create and the messages their designed outputs convey. A case study by Chance and Cole (2015) illustrates how buildings can implicitly or explicitly communicate values to their occupants. When designed with purpose, buildings can instruct new generations and guide users to recognize or assimilate lessons about environmental care, collaborative work, preservation of natural habitats, and efficient utilization of natural resources such as wind, sun, vegetation, and rainwater. This design philosophy can also be applied to engineered products in addition to buildings and structures.

Policy issues

Policy-making is an integral part of changing behavior, and engineers and engineering academics should be involved in this process. This section highlights some policy-related issues that are highly relevant for PNE: *energy justice*, *energy democracy*, and *self-imposed engineering limits.*

Energy justice describes the fair and ethical distribution of energy and alleviates the currently unequal degradation (environmentally, ecologically, and socially) caused by energy extraction. Stephens (2021) highlights the historical and racial imbalances in energy use and the mounting adverse effects of energy extraction and combustion on marginalized communities. Although getting more people access to electric power is desirable to improve living conditions, Stephens asserts that simply scaling up existing systems will inadvertently maintain disparities. Furthermore, technical approaches to counteract global warming may have unintended consequences (Stephens et al., 2021). Stephens presents the term *energy democracy* to promote social equity during the shift to electrification based on renewable energy. Considering these broad impacts when shaping and debating policy is important, and engineers should be part of this dialogue (Stephens et al., 2021).

Looking closely at the engineers' role, Lawlor and Morley (2017) postulate the necessity for engineering professional bodies to set and adhere to *self-imposed engineering limits*, concerning, for instance, carbon emissions, especially in situations where the government fails to enact adequate regulations that can keep profit-prioritizing clients in check. Lawlor and Morley assert the urgency for immediate measures to assist engineers and design teams in counteracting environmentally (and socially) detrimental design briefs. Given the plethora of interests that engineers must navigate, these professionals need more tools and policies and more reflective practices to ensure higher levels of sustainability across development, artifacts, and production processes. Within the framework of PNE, these points are pivotal. Carbon isn't just an isolated metric. Its impact should be understood from a broader perspective, and other factors that influence climate in their own way (factors like methane and nitrous oxide, as well as deforestation) should be included. Such insights are vital as engineers seek to weigh benefits against trade-offs more effectively in complex, unpredictable scenarios.

Fostering public dialogue

It is important to note existing techniques for soliciting stakeholder feedback that engineering practitioners and teachers can use to help lead change. Essential strategies include *public participation* (engaging the public in project initiations and developments), *future thinking* (projecting and planning by envisioning a range of possible scenarios), and *participatory technology assessment* (collaborative evaluations of new technologies; for more on this, see Chapter 18). These existing tools must be part of education to help a broad and diverse array of stakeholders deeply understand and reflect upon issues. Internal and external dialogue must occur for these tools to be effective. The process can articulate a new vision and/or paradigm for a healthier, more sustainable future.

The values of humility and precaution

Given the enormous complexity of the issues identified above, will it be feasible for engineering to deliver the right solutions? We contend that yes, doing so will demand recalibrating engineering to resonate with post-normal times. This will shift engineering closer to decision-making, reaching beyond conventional problem-solving. PNE is tailored to offer knowledge-driven solutions to intricate and tumultuous political challenges by the very fact of its participatory approach, involving the *extend peer community*. This isn't to say that engineering solutions are the sole answer; rather, they must work in tandem with other solutions. Therefore, in post-normal times, PNE practitioners, policy-makers, and advocates should operate humbly without harboring a singular mindset, overemphasizing their solutions, or portraying their approaches as the only path forward. As suggested before, reflexivity is essential to *fostering humility*. *Practicing reflexivity* can help engineers and the engineering community (comprised of practitioners, teachers, and students) continually assess the broader context and their role. This also holds for the choice of ethical frameworks guiding PNE in concrete circumstances. All constituents must anticipate and mitigate potential negative consequences in an unpredictable environment. Although predicting these in every instance isn't feasible, implementing strategies for ongoing monitoring, early warning detection, and timely interventions is essential within PNE.

The *precautionary principle*, sometimes called the *principle of caution*, offers a guideline for handling uncertainties and potential risks. It argues that if an action (e.g., a policy, product, or behavior) could potentially harm individuals or the environment, especially when scientific consensus is absent, we should refrain from implementing it. Tracing its origins to the *safety culture* concept, which emerged in a 1987 report focused on preventing nuclear catastrophes, the term *safety culture* now describes an institutional ethos that prioritizes safety, embedding it in every aspect of operations. Yet, in post-normal times, more in-depth scrutiny is warranted. Delving into an organization's safety culture can benefit from Schein's (1992) layered framework, which examines basic assumptions, stated values, and tangible artifacts. This framework proposes that beyond examining the explicit or professed values of engineers and their affiliated institutions, evaluating the tangible products they produce regarding environmental safety is imperative. Furthermore, it's crucial to challenge foundational beliefs about our relationship with the world, such as the perceived divides between humans and nature or mind and body.

As mentioned above, this approach to envisioning involves engaging in *future thinking* or visualizing potential future scenarios. The process employs divergent thinking to embrace uncertainty and identify many possible solutions. Traditionally, engineers have been trained with an analytical mindset, focusing on deconstructing problems and addressing them straightforwardly and efficiently.

Precaution can involve avoiding potential problems. The *problem avoidance* approach aims to solve a given problem by looking beyond or 'upstream' of the immediate, to alter the larger system, and to prevent the problem from occurring in the first place. Engineers are typically comfortable with the idea of *problem avoidance* because many engineers are attuned to convergent thinking. Convergent thinking aims to find the 'correct' solutions and minimize uncertainties. It is more aligned with traditional engineering mindsets than the divergent thinking needed to brainstorm/project/envision a vast array of possible consequences and outcomes. Incorporating divergent thinking alongside problem avoidance can enrich engineering and engineering education, fostering a more comprehensive approach to addressing complex challenges and promoting ethical decision-making.

Remediating adverse environmental impacts

Engineers often deal with remediating adverse environmental impacts that have already happened. Post-normal engineers are among those concerned with remediation, yet existing practices for addressing current anthropogenic problems sometimes lack full recognition of the causes of the anthropocentric problems. Some curricula in engineering build an understanding of anthropocentric environmental impacts through assessments and measurements, as well as dealing with the consequences of such impacts. Still, they often have false dichotomies embedded in their underlying structure that reinforce superficial notions of separation between the material and the social – and between humans and non-humans (Hawkins et al., 2017). False dichotomies can lead engineers to view environmental problems as a reality independent of cultural and societal practices. Ethical frameworks in environmental education must consider perspectives that move away from separating nature and people and stop placing humans at the fore in most problem-solving. Responsibility, environment, and climate are transversal concerns that all the different types of engineers need to think about.

Undoubtedly, engineering practice and the products engineering produces have enormous effects in multiple realms. Environmental impact procedures exist and are part of official policy in many localities. Yet, there must be more assurance that ethical frameworks (named above and detailed in Chapter 2) inform the legally required assessments. We offer this chapter to provoke more (current and future) engineers to push further and question the bounds of engineering thinking to incorporate deep reflections of an ethical nature.

The value of reflexivity in education as a fundamental ethical attitude for PNE

Recent discussions have highlighted ethical values like *precaution*, *transparency*, *openness* to diverse knowledge and viewpoints, and *accountability* as essential guides for engineering practice. Reflecting on these values in the context of PNE, we wish to underscore *reflexivity* as a pivotal ethical approach for this era.

At its core, any ethics education seeks to cultivate a heightened sensitivity toward ethical dimensions of thinking, behaving, and decision-making. With this in mind, we envision PNE as a discipline that acknowledges the inherent complexities of its practice and actively reflects upon the values of itself and others. This reflection must encompass a broad spectrum, including individual and collective rationales, interests, aspirations, beliefs, and concerns tied to specific challenges.

Reflexivity can be the bedrock for precaution, transparency, openness, and accountability. By fostering this reflexive mindset during engineers' formative years, teachers can help (future) engineers better engage with and appreciate ethical perspectives such as *deep ecology*, *sustainability*, and *land ethics*. Reflexivity represents a foundational practice to support ethical competence in thinking and being. Reflexivity doesn't emerge in a vacuum, though; it is nurtured through dialogues that probe the ethical dimensions of engineering. Cultivating the ability to reflect upon one's and others' values starts with exposure to and deliberation upon a diverse array of ethical frameworks. These might range from traditional anthropocentric theories to the more environment-centric approaches detailed in this chapter.

Engaging in dialogue and informed discussions is indispensable in engineering ethics education. Such interactions bolster ethical competence and unveil diverse (and sometimes conflicting) beliefs and viewpoints prevalent among engineers. Engaged dialogue fosters a richer, more nuanced understanding of engineering ethics than traditional teacher – pupil lecturing can.

Conclusion

This chapter has introduced PNE as an approach for developing sociotechnical strategies and solutions to urgent complex problems. Such engineering practices must be *humble* – because their intended effects and broader implications are uncertain – and *reflexive* – as different perspectives and possible ways to address crises must be discussed and considered. When working on urgent complex problems, ethical dilemmas will occur, and engineers must be able to identify dilemmas and reflect on how to transcend them. The chapter has presented a selection of frameworks and concepts that might be relevant for PNE practitioners. The frameworks and concepts introduced here highlight different ethical concerns, some of which are neglected or at least treated briefly in engineering ethics education research. Although we have aimed to be comprehensive, the 'ideas and frameworks' presented above are merely a starting point. We invite readers to join this dialogue, building upon and refining these foundational concepts in the ever-evolving domain of engineering ethics.

Overall, we have advocated PNE as a reflexivity lens and sketched an emerging vision of what PNE might look like. Fleshing out and realizing this vision is, of course, a work in progress. It will require collective and reflexive effort from a community of diverse thinkers, engineering educators, and practitioners. Essentially, via this chapter, we have launched a call for participants to join the discussion on PNE and reflexivity and use these concepts to facilitate a marked change of direction – a new paradigm for thinking and being – that draws from yet reacts to today's 'normal' engineering practices. We call you to join our community, working toward a more rigorous and reflexive way of addressing global crises through engineering and design.

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