Taylor & Francis
Taylor & Francis Group

Australasian Journal of Engineering Education

ISSN: (Print) (Online) Journal homepage: https://engineersaustralia.tandfonline.com/loi/teen20

Training responsible engineers. Phronesis and the role of virtues in teaching engineering ethics

Giovanni Frigo, Florian Marthaler, Albert Albers, Sascha Ott & Rafaela Hillerbrand

AUSTRALASIAN JOURNAL OF ENGINEERING EDUCATION
https://doi.org/10.1080/22054952.2021.1889086

ARTICLE

Training responsible engineers. Phronesis and the role of virtues in teaching engineering ethics

Giovanni Frigo [a], Florian Marthaler [b], Albert Albers [b], Sascha Ott [b] and Rafaela Hillerbrand [a]

[a]Institute for Technology Assessment and Systems Analysis (ITAS), Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany; [b]Institute of Product Engineering (IPEK), Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany

ABSTRACT
Engineering ethics courses aim to improve students' ethical competence by developing skills such as ethical sensitivity, awareness, analysis and judgement. We present a type of virtue engineering ethics that bridges the gap between academic knowledge (in both ethics and engineering) and its application in engineering practice (particularly design). To clarify why learning about virtues can enrich students' ethical thinking and competences, we specifically consider the virtue of practical wisdom, phronesis. At the core of the paper, we put forward a theoretical argument for including phronesis in teaching ethics within innovation courses. Training this virtue will help engineering students in dealing with the various uncertainties that will emerge from their future engineering practices. With regard to implementing our proposal, we suggest to integrate practical wisdom in 'semi-technical' courses that combine theoretical in-class learning and practical design experiences. We discuss the structure, aims and assessment methods of an integrated product development course that we deem preferable to and potentially more effective than stand-alone engineering ethics classes. An engineering virtue ethics can help engineering students develop a personal reflective way of thinking about concrete courses of action in engineering practice, and may have beneficial ripple effects on their lives, society and the environment.

ARTICLE HISTORY
Received 5 April 2020
Accepted 8 February 2021

KEYWORDS
Phronesis; virtues; engineering ethics; uncertainty; integrated product development; innovation

1. Introduction

The emergence of engineering ethics (Harris et al. 1996; Martin and Schinzinger 2009) attests to the recognition that engineering is inextricably interwoven with ethical issues (van de Poel and Royakkers 2011; Fleddermann 2012; Peterson 2019; Whitbeck 2011). An assumption is that studying the moral dimensions of engineering will ensure that young professionals will be cognisant of ethical implications in their engineering practice. More ambitiously, engineering ethicists aspire to spark an interest in the ethical implications of the profession so that engineers will be equipped to explicitly promote the public good and act in moral ways. The Accreditation Board for Engineering and Technology (ABET) states that ethics in engineering education should help students develop 'an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts' (ABET 2019, 5). Codes of engineering ethics such as that of the National Society for Professional Engineers establish the engineer's paramount obligation as protecting public safety, health and welfare.

Of course, being knowledgeable about the ethical implications of engineering practice is especially important when engineers face moral problems and dilemmas in controversial situations. For example, a team of engineers might have to choose among different options in the construction of a bridge. The ramifications of this deliberative act of decision-making will affect many other individuals over a long period of time. However, reaching an agreement about the most suitable solution is not just a technical matter; it also depends on certain values such as profit, safety or aesthetic preferences. This is where ethical knowledge becomes particularly valuable.

How best to instil this knowledge, however, is debated and there is indeed vast literature on the pedagogy of engineering ethics. Some of the most interesting debates revolve around the best ways of teaching ethics to engineers (i.e. pedagogical methods) as well as reflective attempts to explore and define the specific goals of engineering ethics education: What kind of ethical knowledge should engineers learn? How should ethics be taught in engineering programmes? About two decades ago, Haws (2001) summarised 42 papers about engineering ethics, highlighting the six most common pedagogical techniques used (some of which can of course be combined): moral training according to professional codes of ethics, analysis of humanist readings, discussions about ethical theories, ethical heuristics or decision-

CONTACT Rafaela Hillerbrand rafaela.hillerbrand@kit.edu ITAS, KIT Postfach 3640 76021 Karlsruhe

making tools, case studies, and service learning. Of these methods, the study of ethical theories and their application to case studies relate directly to our proposal.

This approach often comprises an overview of the main branches of ethical theory: consequentialism (effects-based), deontology (rules-based), and sometimes other approaches such as virtue ethics. According to Schmidt, deontology 'encourages adherence to rules and fulfillment of duties or obligations' while consequentialism 'evaluates morally significant actions strictly on the basis of their actual or anticipated outcomes' (Schmidt 2014, 985). Common textbooks present the core tenets of the main ethical theories and then ask students to use them as theoretical 'lenses' to frame and analyse specific engineering case studies in order to evaluate options, form judgements and take decisions (van de Poel and Royakkers 2011; Harris et al. 2019). Case studies are typically concrete examples that are considered problematic (e.g. the limits of bioengineering), paradigmatic (e.g. the 1986 Space Shuttle Challenger disaster), or controversial (e.g. the Three Gorges Dam in China). These cases should not only inform students but also challenge and push them to think 'outside the box' about different perspectives and values. The various principles, rules and criteria offered by each theory can then be used to evaluate the moral merit of different actions and decision-making scenarios (e.g. whether action 'x' is good/bad, option 'y' is right/wrong, proposal 'z' is just/unjust and so forth), providing the students with tools to perform ethical analyses and assessments. For example, an engineer who understands ethics as primarily following the rules of her country's professional code of ethics could be said to embrace a deontological approach. An engineer who acts in a way that maximises the benefits for the greatest number of people would tend to follow a consequentialist perspective, that is one focused on the effects. Overall, teaching ethical theories applied to case studies has the merit to provide students with a variety of ethical outcomes, improving their ability to evaluate concrete examples of decision-making and develop best practices.

However, analysing case studies using ethical theories has a major downside: students learn engineering ethics primarily, if not exclusively, as a theoretical discipline. While a theoretical approach might inspire some students to act ethically in their careers, the risk is that many will ultimately consider their engagement with ethics only as a professional affair, a part of their academic training that is distant from their real lives. Moreover, such moral tools might not help the future engineer when she is researching new technologies and designing new artefacts or processes that may have unprecedented ethical implications, such as the recent advances in genome editing or the potential advent of nuclear fusion. All this raises a fundamental question for engineering ethics: how can ethical theories be applied to unprecedented situations and cases full of uncertainties?

Although we acknowledge the pedagogical potential of teaching moral knowledge through ethical theories and case studies, we contend that, in order to be capable of responding to the above question, engineering students must not only learn about ethics theoretically but also experience it in more applied, dynamic and intimate ways. So, how can we ensure that ethics speaks to young engineers as a concrete and pivotal aspect of their lives and their future professional practice? We argue that an engineering ethics must bridge the gap between theoretical considerations of philosophical ethics and the practical, real-life problems the prospective engineer will encounter both as a person and as a professional. We maintain that virtue ethics may prove particularly useful for this purpose, but only if it is not merely taught as an ethical theory. More specifically, we suggest that a virtue-based engineering ethics should be understood and taught as a mixture of theory and practice that aims to strengthen the notion of the 'good engineer'[1] (Harris 2008). In line with Aristotelian thinking, we envision (the teaching of) engineering ethics as a balancing act that rejects deficits and excesses. That is, we oppose the notion of engineering ethics as the bare-minimum compliance to codes of ethics but also remain wary of hyperbolic formulations such as 'heroic engineers' (Broome and Peirce 1997; Madhav 2014). Instead, we propose that engineering ethics should strive for moral standards of 'goodness' with the ambitious but achievable goal of training virtuous engineers.

In considering the benefits of a virtue-based engineering ethics, our first hypothesis is that learning about the Aristotelian virtue of *phronesis* – a particular kind of practical wisdom – will help engineers in addressing intellectual aspects of their work as well as in making moral choices. Following a review of contemporary approaches that explicitly or implicitly highlight virtues in teaching engineering ethics (section 2), section 3 makes the case for teaching phronesis as an 'ethical mediator' that enables engineers to face a central issue in engineering practice: uncertainty. In section 4, we present how engineering ethics is integrated in a current course at the Karlsruhe Institute of Technology (KIT). We then propose in section 5 an updated version of an Integrated Product Development (or IP, Integrierte Produktentwiklung) course promoted by the Institute of Product Engineering at KIT (IPEK). Our secondary hypothesis is that because such semi-technical course mimics decision-making in industry, it is a good context where students can exercise the complex virtue of phronesis. As part of the mission of the newly established Academy for Responsible Research, Teaching and Innovation (ARRTI) at KIT, we propose an updated version of such IP course, describing its structure, pedagogy and assessment methods. While the first hypothesis is conceptual, the second requires empirical validation that will be part of future research given that the course implementation is scheduled for the winter semester 2021/22.

2. Virtues in engineering ethics

In recent years, within both ethical theory and applied ethics there has been a revival of virtue ethics as an alternative to deontological and consequentialist (predominantly utilitarian) approaches. A traditional categorisation of these three branches of ethical theory posits an important distinction between virtue ethics on the one hand and deontological and consequentialist theories on the other: scholars who embrace the latter tend to focus on determining the 'right actions' that an engineer should perform in specific situations and various contexts, while those who support the former focus on a person's character. Virtue ethics is concerned with determining good qualities or characteristics of an individual, that is, the kind of person a virtuous engineer should be(come). It stresses the character of individuals who are concretely affecting the lives of other people. The assumption of any virtue ethics, then, is that a virtuous engineer will likely perform a moral or virtuous action when needed. Although we are aware of the possible criticisms of this assumption, we maintain that in most cases a virtuous person will exhibit virtuous conduct.

Defending a virtue ethics approach in teaching engineering ethics, Schmidt (2014) listed at least three reasons why a virtue ethics approach would be preferable in engineering ethics. First, deontological and consequentialist approaches 'attempt to impose universal principles that are supposed to govern actions in every situation, while virtue ethics is more heuristic and focuses on developing attitudes' (992). Second, deontological and consequentialist ethics are 'preventive,' that is, they have a negative orientation whereas virtue ethics is aspirational. Third, deontology and consequentialism tend to be impersonal, thereby exacerbating the disconnect between engineering work and actual people. Schmidt affirms that 'sensitivity to context and practical judgment are indispensable in particular concrete situations' (985). On a similar note, Pierrakos et al. (2019) point out that 'engineering ethics education places a heavy emphasis on compliance or rule-following, which provides fewer opportunities for internalizing moral values and virtues' (1). They also stress that virtue ethics and character education deserve more consideration in engineering ethics. Virtue ethics, they assert,

> focuses on the more ordinary and habitual actions, motivations, and virtues that ultimately play a role in everyday life and prepare us for difficult situations. Ethics should inform not only what engineers decide in rare, extreme moments, but also how they orient to daily problems, treat their colleagues and clients, and relate to various stakeholders in the community. (4)

These recent investigations about the role of virtue in engineering education are in line with what Harris wrote more than a decade ago in one of the seminal papers about the professional virtues of engineers. Discussing virtues such as sensitivity to risk, awareness of the social context of technology, respect for nature, and commitment to the public good, Harris (2008) stressed that 'virtue ethics is a more appropriate vehicle for expressing these aspects of engineering professionalism' than negative or precautionary accounts, which he labels 'preventive ethics' (153). Moreover, he stated that an educational approach based on virtues is better suited to address issues of 'discretion and judgment and also for inner motivation and commitment' (153), blurring the lines between professional and personal virtues and, thus, ethics. Similarly, we suggest that an engineering ethics approach that is directly focused on becoming virtuous in an Aristotelian sense – whereby virtues can be acquired through learning (intellectual virtues) and habituation (moral virtues) – can be both fruitful and innovative.

We also maintain that the moral obligations of engineers should not derive solely from a code of ethics. In fact, their duties are defined by the dependence of the whole society on their work, at least for acts of technical design. Engineers thus bear a heavy responsibility towards clients as well as employers, neighbours as well as co-workers, end users as well as all animate and inanimate beings who are transformed, in one way or another, by their technical acts (Brodeur 2013). Although it is ambitious, we view this path as promising because an education that focuses on character 'can assist the end of protecting the public in ways that no list of required courses of action can specify' (Pritchard 2001, 394).

2.1. Virtues and the goals of engineering ethics education

Since at least the mid-1990s various authors have attempted to list the desirable learning goals and outcomes of an ethics education for engineers (Harris et al. 1996; Davis 2006). In a recent survey of engineering ethics programmes throughout the United States, Hess and Fore grouped the main learning goals described across these programmes into three main categories: (1) ethical sensitivity and awareness; (2) ethical judgement, decision-making and imagination; and (3) ethical courage, confidence and commitment (Hess and Fore 2017). The general agreement on the importance of these basic ethical competencies seems to extend to the fact that 'active learning' techniques are more effective than 'traditional' methods (Freeman et al. 2014). Moreover, many authors stress the importance of students not just being taught ethical competencies, but also being systematically assessed and evaluated in their proficiency.

It is interesting that these goals comprise, suggest or imply personal qualities, dispositions or virtues that engineers are expected to acquire through their academic ethical training. The literature on teaching virtue ethics discusses a variety of instructional techniques (e.g. Mintz 1996), including the use of case studies, collaborative and cooperative learning, examples from video presentations, or the technique of role-playing. This latter is often highlighted as providing a particularly fruitful environment for the development of critical thinking, a core component of developing Responsible Research and Innovation, or RRI (Simkins and Steinkuehler 2008). As anticipated above, we are of course not the first scholars to advocate for the use of virtues in engineering ethics.

A virtue ethics approach has already been proposed in the context of scientific research generally (Resnik 2012) and engineering ethics specifically (Harris 2008; Robinson and Dixon 1997; Carbajal and Chavez 2007; Hillerbrand 2006). Zagzebski's foundational work established a theory of knowledge based on the model of virtue theory in ethics, stressing the importance of both intellectual and moral virtues (Zagzebski 1996). In her proposal to develop mentoring for young adults concerning the development of social responsibility, Brodeur (2013) stresses cooperative and service learning as ways to enhance social responsibility. Framed in terms of ethics of care (indeed often related to virtue ethics), her list of principles of social responsibility can be understood as virtues: compassion, solidarity, charity and care for the poor are traits that for Brodeur should be central in engineering education. In an article reflecting many of the elements that will be explored below, Schmidt (2014) distinguishes between moral and intellectual virtues in engineering and provides 'a comprehensive framework for implementing virtue ethics within engineering' (985). Han (2015) argues for a 'New Model of Science and Engineering Ethics Education' wherein students experience moral modelling and involvement in real moral activity in science and engineering ethics classes based on a conceptual framework that merges virtue ethics and positive psychology. In particular, we agree with his claim that 'the most important way to develop a person's morality in terms of virtue ethics is the cultivation of moral virtue through the early habituation and internalisation of moral virtue' (451). This accords with the Aristotelian notion that developing a virtuous character requires the habitual repetition of virtuous acts. This emphasis on knowing what virtuous conduct is in order to do it repeatedly underscores, again, that a virtue-based engineering ethics should combine theoretical and practical aspects. Moreover, Sand has scrutinised the virtues and vices of technological pioneers and their significance for innovation processes (2018). For Pierrakos, virtue ethics 'is the theoretical foundation of character education, a theory of moral education that focuses on helping individuals develop stable and enduring virtues of character that dispose them to think, feel, and act in morally appropriate ways' (Pierrakos et al. 2019, 4). This innovative emphasis on the role of emotions has also been proposed in the context of RRI (Steinert and Roeser 2020) and within engineering practice specifically (Roeser 2012). Similarly, a proposal to focus on 'empathy and ethical becoming in biomedical engineering' has been proposed by Hess et al. (2020), who suggest that the ethical training of biomedical engineering students should include 'ethically sensitive, emotionally powerful, and visceral experiences' (1). Vallor (2016) has proposed an approach to ethics of technology based on what she calls 'technomoral virtues'. While her take on phronesis differs from ours, she considers it a central virtue too. Specifically, in her proposal to create 'a technomoral virtue ethic of global scope' (2016, 64), practical wisdom plays a central role by guiding both individual and collective decisions. Koehler et al. (2020) offer a literature review of 'four prominent virtues in engineering education,' namely '(1) critical thinking (an intellectual virtue), (2) empathy (a moral virtue), (3) service (a civic virtue), and (4) teamwork (a performance virtue)' (2).

2.2. *Phronesis in engineering ethics*

English translations of Aristotle's *Nicomachean Ethics* (*NE*) render the term *phronesis* (Ancient Greek: φρόνησις, Latin: phronēsis) in various ways. Here, we will adopt the expression 'practical wisdom' because it conveys a type of reflective reasoning connected to concrete courses of action and their possible effects. Phronesis is an intellectual virtue (i.e. learned through instruction) that is very closely connected to the moral virtues because it helps practice them properly. The Aristotelian phronesis directs, modulates and helps actualise a person's moral virtues, adjusting their expression according to the unique moral demands of each situation. A fully virtuous person, then, is never blindly or reactively courageous or benevolent. Rather, her virtues are expressed intelligently, in a manner that is both harmonious with her overall character and appropriate to the concrete situation with which she is confronted (*NE* 1134b10–17). Similarly, we argue that the virtue of phronesis can provide useful guidance in the uncertain landscape of responsible engineering. Furthermore, virtue ethics stresses the existence of an intimate connection between being virtuous and a personal state of fulfilment or happiness (*eudaimonia*). Phronesis plays a fundamental role here: it develops constructive engagement with the available options and boundary conditions of one's actions, mediates between extreme positions (vices), enables one to choose the right action, and hones the ability to choose wisely, that is, in a balanced and reflective way (see also (van de Poel and Royakkers 2011, 98). This, in turn, would practically benefit the individual agent because the person who acts in a virtuous manner is also more likely to be more fulfilled and accomplished.

Some authors have already proposed that phronesis be adopted in professional ethics. For example, Hillerbrand (2008) discusses dianoetic virtues, among which phronesis, in the context of geneticallymodified organisms. Marcum (2009) explores the role of both theoretical (intellectual) and practical (moral) virtues in shaping the character of the 'epistemically virtuous clinician': intellectual and moral virtues contribute to practical wisdom, described as 'the wise and judicious application of the fruits of theoretical wisdom to decisions about actions or commitments in specific, concrete situations' (2009, 262). About phronesis in engineering, Moriarty (2009) asserts:

> It is through phronesis that we discern and choose appropriate goals of ethical virtue. Thus, ethical virtue without phronesis remains directionless. But discernment of the good and perfection of deliberation are dependent on having a good character. Hence, without ethical virtue, one might be able to Wgure out an appropriate end, but one would not be able to choose the proper means. And without phronesis, one might be able to choose the appropriate means but not the right end. Excellence of character, then, and practical wisdom together form a unity. (136)

Itabashi-Campbell, Perelli, and Gluesing (2011) discuss how phronesis can also become instrumental in engineering problem-solving as part of a specific 'engineering epistemology' (See also, Itabashi et al. 2012). In his comprehensive framework for implementing virtue ethics within engineering education, Schmidt (2014) states that phronesis resembles the critical competence of 'engineering judgement' and is 'knowledge-how to behave in a manner that is contextually sensitive and appropriate' (987). Hillerbrand and Roeser (2016) suggest that emotions related to risk perception and art can constitute two alternative ways of learning and practicing phronesis. Finally, Costello has devoted several articles to how phronesis can be developed in educational practice, specifically in the curricula of management, engineering and business students (Costello 2018, 2019). Concerning teaching tools and methods, Costello illustrates a compelling case study about how to embed the concept of phronesis in an educational module at the Galway-Mayo Institute of Technology. He discusses a course where cross-functional teams of engineering and business students worked together on an entrepreneurial project, with the goal of tapping into the potential for turning entrepreneurial ideas into commercial businesses while exercising phronesis. Costello's example resembles our idea of integrating phronesis into an innovation course, as we will detail in our proposal below (section 5).

3. Two arguments for the empowerment of phronesis in engineering ethics

Authors who argue for a revival of virtue ethics often claim that, especially after the Enlightenment and its focus on scientific rationality, the notion of phronesis as a judgement concerned with moral goodness lost its importance. Höffe (1993), for example, argues that with Kant judgement was decoupled from ethical reasoning. According to him, the notion of phronesis as genuine ethical reasoning is replaced by that of cleverness or smartness, the latter being at best morally neutral (260–-266). Luckner (2005) also suggests this when he considers that, with Kant, phronesis loses its moral function and becomes a 'private matter.' In this sense, the goal of morality is no longer the realisation of the morally good (Aristotelian *eudaimonia*, happiness or fulfilment), but instead becomes concerned with individual autonomy or the rational justification of individual purposes. In this way, phronesis resembles a personal technique about luck and cleverness.

However, in the following, we contend that in order for an ethics of engineering to be fruitful, this decoupling of the rational from the moral must be revised and the two aspects reunified. This would mirror the recognition that many engineering problems often imply both epistemic and moral dimensions. What must become central in teaching engineering ethics is a notion of phronesis as a type of practical wisdom that is a priori focused on the morally good. In the following, we offer two reasons for this: One is based on the creative nature of engineering practice in general and becomes visible in the mediating power of phronesis (3.1). The second reason depends on the necessity for engineers to deal with uncertainties and suggests that phronesis can indeed play a key role in engineering creativity (3.2).

3.1. Phronesis as an ethical mediator

The essence of engineering practice is to create new knowledge or artefacts; by its very nature, this characteristic necessitates fairly vague ethical principles that in turn need to be connected to concrete engineering practice. Following Höffe (1993) and Hillerbrand (2006), we argue that phronesis fulfils this mediating role. Moreover, practical wisdom serves a second function: it performs a 'balancing act' in accordance with Aristotle's advice to adopt a middle way between extremes (vices), sometimes also known as the rule of the 'golden mean'.

Both the creation of engineering knowledge and the design of artefacts or processes are aimed at changing our living environment and enhancing the convenience and beauty of our everyday lives (Martin and Schinzinger 2009). In this, engineering and scientific practices are always creative. General references to moral duties or moral values are of limited use as engineers and scientists typically create new decision situations that have few, if any, analogies in the past. This holds particularly, but not only, for so-called disruptive technologies.[2] Note that in contrast to medical ethics (Beauchamp and Childress [1979],2012), in engineering ethics, there is not even an agreed-upon set of accepted mid-level ethical principles.[3] Here phronesis could act in its mediating role of applying general rules to specific design or research requirements. For example, a virtuous engineer may ask whether a proactive, risky approach or a precautionary one is more appropriate in a specific decision situation. This involves an epistemic component (i.e. judging the available probabilities), and an ethical component (i.e. reasoning about what is at stake morally). Both are tasks performed by phronesis, whose role is of central importance in, for example, sustainability analysis, where engineers must question assumptions held as facts by the general public concerning the evolution of certain technologies, such as a seemingly sustainable technology that may turn out to be in fact unsustainable.

The tasks of phronesis, however, extend well beyond this mediating role. For example, in complex engineering settings such as the CRISPR/Cas method in genetic engineering, the boundaries of our knowledge are pushed beyond existing frontiers. In such specific context, phronesis would help identify certain decision situations and actions as ethically relevant. As such, phronesis is not ethically neutral but normative in prescribing morally appropriate decisions and courses of actions. As engineering ethics often deals with (at least partially) new decision options that only become available through technological progress, phronesis may serve a further function in a role of detection. Only by identifying ethically relevant decisions and situations in specific engineering practices can an ethics of technology identify and determine ethically relevant situations as such (Cf. Mathwig 2000). In this sense, new research can create new issues, but we should not wait for these issues to become political problems. Engineers can play a role here by gaining some expertise in ethics in order to identify and address ethical challenges already in the early design stages. Without this familiarity with moral standards, any ethics of technology or engineering ethics is doomed to simply accept and follow what the general public identifies as an ethical problem, which typically happens after a new technology has been developed (as many consequentialist would do). So far, we have focused on engineering design and technological reasoning as a general creative practice and argued that it is therefore crucial firstly to mediate between more general ethical rules and concrete engineering practices, and secondly to identify decision situations as morally relevant. Both tasks are far from straightforward and the Aristotelian concept of phronesis may allow to capture only some of the intellectual and ethical challenges that emerge.

3.2. Phronesis in dealing with uncertainties

Another prominent manifestation of engineering creativity consists in the way engineers deal with the various uncertainties they face in their practices (Cf. Poznic et al. 2020). Designing complex products involves working with uncertainties as the product, its requirements and the environment in which it is used co-evolve, and designers and external stakeholders make decisions affecting the evolving design. All too often the presence of uncertainties regarding the final product and its concrete implications is used as an excuse to not address ethical considerations in the early design phase. However, this is the appropriate time for amending the product according to ethical standards. Given this issue, an approach based on virtue ethics allows a shift in focus from evaluating actions to evaluating the agent, specifically, the character traits that result in certain types of actions.

Phronesis may also be able to help in addressing uncertainties. Before we delve into that, let us briefly consider some typical examples of how uncertainty may hamper ethical evaluation in engineering practice and how classical risk or uncertainty analysis has been so far unable to deal with these problems. In reasoning about the safety of the civil use of nuclear power, risk is commonly defined as average harm, i.e. harm times the probability of its occurrence. For example, we may know the probability that a certain valve in a nuclear power plant will start leaking after 10 years. We can then estimate the *risk* of an accident. But suitable probability estimates are not always available, as in the case of the risks associated with the disposal of nuclear waste from a reactor. We may be able to assign some probability to the stability of the rock formation over the next hundred years or so. But when it comes to longer time scales (e.g. 24,000 years, the half-life of a plutonium isotope, or 1 million years, the time span the German government requires nuclear waste disposals to be safe), there are certainly no reliable probabilities in the form of relative frequencies. In technology assessment or decision theory, one refers to these types of decision situations where no reliable probability estimates (in terms of frequencies) are available as 'decisions under uncertainty', which also raise fundamental questions about 'unknowable ceilings of safety' (Downer 2015) and 'moral experiments' (van de Poel 2015).

In engineering practice, the acceptance or the actual use of an artefact after market release is often highly uncertain too. However, the ethical evaluation depends exactly on addressing these uncertainties as soon as possible. So, decisions under uncertainty are typical of engineering practice, particularly where the long-term or long-range after-effects of an artefact's or process's use are concerned. This highlights yet another challenge for engineering ethics in practice, namely how to frame 'decision making with an indeterminate decision horizon' ((Hansson 1996, 371). Consider another example: in assessing the sustainability of a product, engineers typically employ so-called Life Cycle Assessment (LCA), or more recently also the S(ocial)LCA or LCS(ustainability) A. The outcome of these evaluations is highly dependent on how the system boundaries are chosen. While there are general regulations on how to perform a LCA (e.g. ISO 14,040 and ISO 14,044), there is not much guidance on how to establish system boundaries. Similarly, while there is general agreement about how to decide under risk, decision-making under uncertainty derived from setting systems' boundaries give rise to much disagreement among experts. Indeed, there is not even an established terminology for referring to these uncertainties (Cf. Hansson and Hadorn 2016). Suggested terminologies include 'non-normal science' (Funtowicz and Ravetz 1993), 'wicked problems' (Rittel and Webber 1973), 'great uncertainty' (Hansson 1996) or 'deep uncertainty' (Lempert et al. 2004). Nonetheless, and despite great advances in formal approaches to uncertainties, there is a growing consensus that these approaches and terminologies have reached their limits and are in need of some kind of supplement. As the intellectual virtue capable of navigating uncertain landscapes, phronesis may provide a useful way to address the challenges of uncertainties emerging from engineering practice (Hillerbrand and Roeser 2016).

4. Current engineering ethics in an integrated product development course

Having established the potential usefulness of phronesis and a virtue-based approach to engineering ethics education, we now turn to our case study. This section describes the Integrated Product Development (IP) course promoted by IPEK – Institute for Product Engineering at Karlsruhe Institute of Technology (KIT) and why we hold that this is an ideal context to integrate a virtue approach and facilitate the engagement of engineering students with phronesis.

4.1. Overview of the project: KaLeP, IPEK and ARRTI

KIT is part of a group of nine German technical universities (TU9). Part of the ethics education takes place at the IPEK, an institute whose fundamental research concept is the parallel research on methods and processes of product development regarding concrete technical systems. In this context, product development is combined with research on the synthesis and validation of new technical systems. An instructional approach that has proven very useful is the so-called Karlsruhe Education Model for Product Development (KaLeP), which has been implemented at KIT since 2006 (Albers, Burkardt, and Tobias 2006; Niever et al. 2020). It originally aimed at an integrated acquisition of technical, systematic, methodological and professional competencies that are difficult or impossible to teach in typical seminar, lecture or laboratory class settings alone. A course on integrated product development combines various educational elements: lectures, workshops, exercises and team projects.

4.2. Overview of the current integrated product course structure

The Integrated Product Development (IP) course[4] is a semi-technical course on product design and development that aims to integrate innovation into engineering teaching and provide students with hands-on competences. Before the course begins there are two preliminary organisational steps: first, finding an industry partner and second, selecting the students who will take part in the programme. Students are selected based on individual interviews and merit demonstrated in previous classes along with a letter of motivation and a test.

Since 2016, the course has included a module called 'Responsibility of Engineers,' in which students learn the relevance of ethical thinking with regard to actions through various examples from engineering practice (e.g. ethical problems associated with autonomous driving). The course includes 20 lectures of 90 minutes each. Of these, one and a half are currently dedicated to ethics. The instructor is an engineer with competence in ethics. Overall, the goal is to highlight and make tangible the potential ethical implications of the product as early as possible in the development process.

Each cohort consists of up to 42 students, divided into six teams (7 people/team). The teams are formed by master students from different fields of study (mechanical and industrial engineering, informational technologies and mechatronics). In terms of organisational integration, every team member has a clear role and specific tasks: spokesperson, method engineer, validation engineer, system engineer, construction engineer, and product engineer. Each team maintains the same composition throughout the term and works collaboratively on the design and development of a specific product.

The main goal of the course is to develop concrete solutions in collaboration with a specific industrial partner (e.g. ThyssenKrupp, Diehl Metering, AVL, Daimler Trucks, Bosch, Siemens, Mercedes-Benz). The industry partner changes every year, defines the problem to be solved, and has an active pedagogical role in the educational process. Every three to five weeks, teams set milestones with the industry partner to polish and guide their specific projects. It is important to note that all teams receive the same assignment at the beginning (see below, section 4.3), but they are asked to find their own way of completing it. In addition to performing an individual and team evaluation every four weeks, the industry partner also provides a mentor for student advising.

The collaboration between the university and the industry project partner offers mutual benefits and opportunities: companies have access to potential new employees as well as intellectual knowledge, especially about methods in engineering (e.g. analysis); students benefit from direct contact with real-life businesses and get hands-on experiences and potential internships; IPEK is able to perform research on methods; and the university accomplishes its mission of educating professionals and linking them to the job market while receiving funding for such projects from the companies. The teams work for five months to implement development tasks under realistic conditions. At the same time, the students work in a research environment that is designed to explore, develop and evaluate processes and methods of product engineering. The setup of the lab environment where the students work combines the positive aspects of laboratory studies (i.e. a made-up problem the students investigate) with the benefits of field studies (i.e. applied product development).

We hold that the mimicking of the industrial practice (i.e. the student teams simulate real working groups in industry) make this course an ideal place for implementing ethical reasoning in the form of practicing virtues. As the students simulate engineering industrial projects they have to deal with the uncertainties emerging from the concrete process from brainstorming to final product. Integrating ethical reasoning in the early stage of the design process as well as discussing the entanglement of ethical and epistemic aspects can be further improved by training virtues such as phronesis.

In the current format, the ethics module takes place at the beginning of the course and then again at a more advanced stage. First, it is integrated in a three-day workshop and consists in applied ethical examples related to the current industry partner. The students are encouraged to address ethical questions arising from their collaborative design work within their respective teams. However, in our experience students do not immediately recognise the relevance of these questions for their industry project. But because ethical questions remain nonetheless central, there is room for improving students' intrinsic and extrinsic motivations.

Currently the assessment of progress is defined together by the teams and the instructor by regularly establishing and updating milestones. During the term, teams have reflective discussions where they evaluate what has gone wrong in different parts of the process and who is responsible for it, including ethical aspects. At the end of the IP course, a 60-minute oral exam offers another occasion for evaluating controversial cases. Presently, this is the only individual assessment in the course as all other assignments and tasks are performed by the teams and evaluated as such.

4.3. A concrete example of ethical training of a team of students in the IP course

The following is a description of a product development case that was part of a previous IP course carried out according to the description above.

Project: water metres, in collaboration with company partner 'Diehl Metering', Germany.

Guiding questions:

(1) What does the water metering of the future look like?
(2) What influence does water metering have on the consumption of water in general (in terms of users' behaviour)?

Working Assumption: As a response to the second guiding question, it is assumed that in the perception of users, water consumption is distinct from water measurement. It is assumed that people are not interested in or committed to knowing about their water consumption (i.e. they do not check the water metre systematically, on a regular basis).

Task: Is there potential for ethics-driven innovation in this context?

Product Ideas and Actual Product Development by Two Teams of Students:

Team #1 designed and produced a small device that can be placed at the outlet of a bathtub faucet. This device changes colour (from green to red) as water consumption increases. According to the students, this solution provides users immediate knowledge about actual consumption and insights into how to reduce it.

Team #2 created a software application for smartphone/watch that allows the user to know how much water is s/he has been consuming. This product is in a way similar to apps about monitoring caloric intake or energy consumption.

5. Proposal for the integration of phronesis within the IP course at KIT

Although in Germany engineering ethics has a fairly long history (Downey, Lucena, and Mitcham 2015, 81), the ethical education of engineering students is not yet standardised or implemented systematically across German technical universities, not even the TU9. The recently created Academy for Responsible Research, Teaching and Innovation, ARRTI, a central project in the KIT's strategy to make it one of the centres of excellence ('Exzellenzuniversitäten') among German universities, aims at integrating the teaching of ethics in all curricula. The explicit goal is that all students at KIT will have received ethical training as part of their degrees. This ambitious project includes efforts to implement a pilot project about integrative engineering ethics modules focused on virtue ethics. The following section describes a blueprint for such an approach by describing an updated version of the ethics module within the IP course presented above. The reason for this is that ethical considerations of the students in the course as it has been designed thus far still remain somewhat distant from both what they perceive to be their job as engineers and from their lives. Students tend to perceive ethics as an external constraint, and ethics in engineering is still seen as a matter of duty, following certain (legal or societal) rules or regulations, rather than a process of active reflection and direction-seeking. Therefore, we identified two interrelated issues within the current setup:

- Ethical considerations and engineering enterprise are perceived as distinct endeavours;
- Ethics is perceived mainly as following external regulations;

Given these challenges and at the same time acknowledging the generally successful experience of the IP course as described above, we believe that it represents an ideal place to experiment with a pedagogical approach based on virtue ethics. The theoretical considerations outlined in section 3 motivate our proposal that students should learn and practice virtues such as phronesis as part of their work on product design and development.

5.1. Overview of the project

In coming terms, the IP course will be the prototype for testing integrated teaching modules in which engineers and ethicists jointly teach and advise students within the newly established ARRTI. In doing this, we will draw on the various didactic concepts outlined in section 4. As anticipated above, some steps in the design process may turn out to be ethically neutral, while others may have a severe impact on, for example, marginalised stakeholder groups, future generations, or the non-human environment. Given that the impacts of new technological artefacts or processes are always fraught with uncertainties, determining whether to opt for a proactive or precautionary approach during the design stage is one of the central aims of ethically guided judgement, the Aristotelian phronesis. Students need suitable lecture modules to prepare them for this type of reasoning, without compromising the other modules. It is equally important to assign coursework that also allows them to reflect on ethical aspects. In this way, developing virtues can become something personal and more intimate. Our approach also stresses the important 'role-model' function that teaching staff and faculty can embrace. Suitable role models for teaching virtues can also be drawn from industry, such as successful engineers who reflect on their decisions from an ethical perspective without necessarily being considered 'heroic'.

While these instructional techniques are valuable and will be used in the course outlined below, we hold that in order for students to acquire phronesis, these techniques need to be expanded. One task of phronesis is to distinguish the possible impacts of one's action as ethically relevant. This is particularly challenging in research and innovation as there may not be any previous examples of similar challenges, i.e. there are no precedents to refer to. It is therefore desirable to train engineers in such a way that they are themselves able to point to potential ethical challenges in the early stages of design and product development. While it is difficult for a class-based approach to simulate the highly context-dependent nature of dealing with uncertainties, this can be achieved more successfully though a combination of in-class learning and practical experiences as it already occurs in the IP course.

In the future, the implementation of out-of-class activities such as internships in the industry partner may provide further opportunities to experience and practice 'ethics as an outcome of out-of-class engagement' (Polmear, Chau, and Simmons 2020), particularly if related to virtues.

5.2. Overview of the course structure

Although the updated course structure remains largely similar to the existing IP course, there are three main differences. First, the new course will be co-taught by two instructors: an engineer and an ethicist (moral philosopher). The engineering instructor will have most of the teaching responsibility and will be present also during the ethics classes, primarily to facilitate interactions and help create connections among topics. Eventually, the course will be able to rely on co-teaching as well as on informed instructors in every team. These instructors will be engineers with a more advanced ethical education. This competence derives from a specific project within ARRTI that is based on the 'train the trainer' concept. In practice, it establishes that engineering instructors will take at least three ethics courses (e.g. ethical theory, role-play, practicing virtues) consisting of online modules as well as in classroom discussion sessions. Second, the ethical component will be expanded, with part of it spread throughout the term through different events, not only in-class activities. Third, there will be various assignments that will better assess the ethical component. As an illustration, consider a standard semester at KIT which typically has 13 lecture sessions.

First Ethics Module – Week 1, 90 min:

At the beginning of each term, there is a three-day workshop for new students where the topic of engineering ethics is introduced through a lecture with interactive examples closely related to ethics (e.g. the VW diesel scandal). There, students examine case studies of new product ideas and begin to understand what it means to think about medium and long-term ethical implications of product development (for a source of case studies directly connected to ethical issues, see, e.g. van de Poel and Royakkers 2011; Harris et al. 2019). This examination is based on a catalogue of criteria and evaluation similar to the failure modes and effects analysis (FMEA) methodology. Basic ideas of ethical reasoning and normative theories are introduced through the case studies and students are actively invited to comment on them.

Assignment: The teams of students discuss and answer ethical questions about case studies.

Second Ethics Module – Week 5, 90 min:

After a brief review of the content introduced in the first ethics lecture, the second module focuses on risk assessment and uncertainties through case studies. Students are already aware of some ethical theories from the initial workshop. In this module, they are further exposed to virtue ethics through examples of ethical dilemmas and ethically controversial product concepts (e.g. a safety device with data collection implications). The instructors will provide a list of ethical criteria for analysis and evaluation. Students perform an initial ethical assessment of the case at hand and discuss the results comparatively. Then the lecture compares these assessments with a virtue ethics approach and hence focuses on phronesis. This means that in this second module students learn about the opportunity to engage with ethics through a virtue ethics approach and, firstly, learn about the notion of phronesis theoretically. Then, through the application to case studies and various moral scenarios, each team is encouraged to explore how a virtue ethics approach would influence their own design idea and product development process. For this purpose, a specific workshop challenges each team to perform an ethical assessment of their own product design by applying the same criteria given earlier in conjunction with virtue ethics.

Third Ethics Module – Bi-weekly Lecture Series (throughout the term weeks 2–14):

Students participate in the lecture series 'Role Models in Action and Thinking' hosted and organised by ARRTI. The lecture series features external speakers from industry and academia who can be considered role models of best engineering practices (i.e. they are successful engineers and entrepreneurs who have discovered that ethics plays a central role in their work). In these events, the guest speakers reflect on their experiences and the ethicist comments on the presentation, helping students recognise the ethical dimensions involved. The students are encouraged to engage in discussion with the speakers. The topic of this lecture series will be in line with each year's industry project.

Assignment:

Each team writes a report on the lecture and reflects on its ethical components. Students are asked to identify relevant character traits of the speakers, in particular virtues. Once phronesis has been introduced, students will also try to show how the role model displayed phronetic traits in their engineering practice. This part of the course earns the students additional credit points as part of liberal arts education at KIT ('Schlüsselqualifikationen').

Fourth Ethics Module – Throughout the Term – Weeks 2–14:

Over the course of the term, each team moves from prototyping their product ideas to creating real, functional prototypes. As they progress, teams reflect with their instructors about the evolution of their project also from an ethical standpoint, addressing whether their initial ethical assessment at the time of design is different from that at the production stage. Students may also be asked to perform ethical reflections on a personal level, that is, individual reflections beyond the ethical criteria provided by the instructor. Finally, an integral part of every team besides the students is a tutor. This tutor is a PhD student or researcher in the engineering department. In order to implement the forth ethics module, the tutors have to be trained in ethics. This is also done as part of ARRTI's 'train the trainers' project, described above.

Final Assessment: Oral examination, an individual test that focuses on the integration of engineering and ethical aspects.

6. Conclusions and outlook

We have shown that the epistemic complexities engineers typically face in their work often make the ethical evaluation of individual actions and their outcomes extremely challenging or even impossible. We proposed that supplementing approaches focused on actions by paying more attention to the development of personal character may help to address some of the issues faced by engineering ethics. We therefore advocated for embodying virtues in the core curriculum of engineering. We have illustrated the epistemic challenges that are intrinsic to engineering design and research through various types of uncertainties that engineers face in practice. We have outlined how teaching virtues can be incorporated in an integrated course on product development where students are able to practice phronesis. We suggested that by integrating ethics into a practical lab course and intertwining the habituation of virtues with the practice of other central engineering skills, teachers may be better able to help prospective engineers understand that ethics is not separate from engineering practice, but an integral part of it as well as of their lives. We hold that the necessity of dealing with uncertainties in engineering practice entangles the epistemic and ethical aspects. Teachers should begin with the epistemic challenges of uncertainty management and then point out the related ethical issues. This strategy would help students appreciate how and why ethics is really integral to engineering practice. Furthermore, exercising phronesis as a means of integrating the ethical and epistemic aspects can help bridge the gap between ethical reasoning and engineering practice.

From an engineering perspective, companies are striving to improve and maintain a high innovation strength (Innovationskraft) in order to remain competitive and help solve pressing social and environmental problems. In turn, this requires medium and long-term research plans as well as virtuous engineers. We have suggested that ethics instruction can become more relevant and engaging for students if, instead of being isolated in a separate class, it is embedded in 'semi-technical' courses such as integrated product development, with both theoretical and practical ethics modules. In this way, students can learn about the theory and experience its practical application. Instead of focusing on the *action* an engineer ought to perform in a specific situation, a student who has learnt about virtues and has had the opportunity to practice them would attach importance to the type of *character traits* that good engineers display. In turn, students should be more motivated to imitate these virtuous examples by acquiring and cultivating virtues, not only in light of their social role and responsibilities, but also to improve their personal lives. Finally, focusing on phronesis as the central virtue in engineering ethics may also prove useful for addressing other challenges in engineering curricula. First, it may help connect academic knowledge (both ethics and engineering) with its application in engineering practice (particularly design). Second, a perspective on virtues may help to bridge the gap between engineers' ethical responsibilities as professionals and their private actions as citizens. As mentioned above, the validation of our hypotheses and the assessment of the actual effectiveness of our course proposal will require implementation, adjustments and additional empirical research.

Notes

1. Interestingly, Bowen (2010) has also explored the notion of the 'good engineer' theologically.
2. See https://ethicsandtechnology.eu/news/4tu-ethics-bi-annual-conference-thursday-7th-friday-8th-november-2019-tu-eindhoven/. Consider, for example, the European Commission's recent Guidelines on Trustworthy AI (2019).
3. Cf. Peterson (2017) for an attempt to formulate mid-level ethical principles.
4. See also: http://www.ipek.kit.edu/3439.php.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by the Karlsruher Institut für Technologie.

Notes on contributors

Giovanni Frigo is a Postdoctoral Researcher in the Philosophy of Engineering, Technology Assessment & Science (PhilETAS) Research Group at the Institute for Technology Assessment and Systems Analysis (ITAS) at the Karlsruhe Institute of Technology (KIT). Born and raised in the Italian Alps, he studied at the University of Verona, Italy, and at the École des Hautes Études en Sciences Sociales in Paris, France. In 2018 he received his PhD in environmental ethics from the University of North Texas (UNT) in Denton, TX, USA. His interdisciplinary research focuses on the fundamental links between ethics and energy.

Florian Marthaler currently works at the Institute of Product Engineering (IPEK), Karlsruhe Institute of Technology. Florian does research in Mechanical Engineering, Electrical Engineering and Automotive Engineering. Their most recent publication is 'Improving R&D Success: Exploring modeling approaches for product profiles'.

Albert Albers, Univ.-Prof. Dr.-Ing. Dr. hc Albert Albers, born in 1957, has been a full professor since 1996 and is today spokesman for the management of the IPEK - Institute for Product Development at the Karlsruhe Institute of Technology (KIT).

Sascha Ott, Dipl.-Ing., Managing Director Institute for Product Development (IPEK), Karlsruhe Institute of Technology (KIT), Managing Director of the KIT Center for Mobility Systems.

Rafaela Hillerbrand is a Professor of Philosophy of Science and Technology and the head of the Philosophy of Engineering, Technology Assessment & Science (PhilETAS) Research Group at the Institute for Technology Assessment and Systems Analysis (ITAS) of the Karlsruhe Institute of Technology (KIT). She holds PhDs in philosophy (2005) and theoretical physics (2008). From 2006 to 2008 she held a position as a senior research fellow at the University of Oxford. Before joining KIT, Dr. Hillerbrand worked as an associate professor at TU Delft and was head of the interdisciplinary research group Ethics for Energy Technology (EET) at the Human Technology Centre (HumTec) at RWTH Aachen University. She serves on expert committees to advise policy and industry on questions concerning the development of sustainable (energy) technologies.

ORCID

Giovanni Frigo http://orcid.org/0000-0002-3121-2773
Florian Marthaler http://orcid.org/0000-0003-2432-4256
Albert Albers http://orcid.org/0000-0001-5432-704X
Sascha Ott http://orcid.org/0000-0002-1691-729X
Rafaela Hillerbrand http://orcid.org/0000-0002-7890-3715

References

ABET. 2019. *Criteria for Accrediting Engineering Programs 2020-2021*. Baltimore: ABET.

Albers, A., N. Burkardt, and D. Tobias. 2006. "Competence-profile Oriented Education with the Karlsruhe Education Model for Product Development (Kalep)." *World Transactions on Engineering and Technology Education* 5: 2.

Beauchamp, T., and J. Childress. (1979) 2012. 7th. *Principles of Biomedical Ethics*. Oxford - New York: Oxford University Press.

Bowen, W. R. 2010. "Ethics and the Engineer: Developing the Basis of a Theological Approach." *Studies in Christian Ethics* 23 (3): 227–248. doi:10.1177/0953946810368021.

Brodeur, D. R. 2013. "Mentoring Young Adults in the Development of Social Responsibility." *Australasian Journal of Engineering Education* 19 (1): 13–25. doi:10.7158/D12-014.2013.19.1.

Broome, T. H., and J. Peirce. 1997. "The Heroic Engineer." *Journal of Engineering Education* 86 (1): 51–55. doi:10.1002/j.2168-9830.1997.tb00265.x.

Carbajal, C., and E. Chavez. 2007. "Trustworthiness and Integrity: Cardinal Virtues for Engineers." *Latin American and Caribbean Journal of Engineering Education* 1 (1): 4.

Costello, G. J. 2018. "Aristotle's Phronesis: Putting Some Meat on the Philosophy of Innovation." In . London.

Costello, G. J. 2019. "The Philosophy of Innovation in Management Education: A Study Utilising Aristotle's Concept of Phronesis." *Philosophy of Management* 18 (3): 215–230. doi:10.1007/s40926-018-00104-7.

Davis, M. 2006. "Engineering Ethics, Individuals, and Organizations." *Science and Engineering Ethics* 12 (2): 223–231. doi:10.1007/s11948-006-0022-y.

Downer, J. 2015. "The Unknowable Ceilings of Safety: Three Ways that Nuclear Accidents Escape the Calculus of Risk Assessments." In *The Ethics of Nuclear Energy*, edited by B. Taebi and S. Roeser, 35–52. Cambridge: Cambridge University Press. doi:10.1017/CBO9781107294905.003.

Downey, G. L., J. Lucena, and C. Mitcham. 2015. "Engineering Ethics and Engineering Identities: Crossing National Borders." In *Engineering Identities, Epistemologies and Values*, edited by S. H. Christensen, C. Didier, A. Jamison, M. Meganck, C. Mitcham, and B. Newberry, 81–98. Vol. 21:. Cham: Springer International Publishing. doi:10.1007/978-3-319-16172-3_5.

Fleddermann, C. B. 2012. *Engineering Ethics*. 4th ed. Upper Saddle River: Prentice Hall.

Freeman, S., S. L. Eddy, M. McDonough, M. K. Smith, N. Okoroafor, H. Jordt, and M. P. Wenderoth. 2014. "Active Learning Increases Student Performance in Science, Engineering, and Mathematics." *Proceedings of the National Academy of Sciences* 111 (23): 8410–8415. doi:10.1073/pnas.1319030111.

Funtowicz, S. O., and J. Ravetz. 1993. "Science for the Post-Normal Age." *Futures* 31 (7): 735–755.

Han, H. 2015. "Virtue Ethics, Positive Psychology, and a New Model of Science and Engineering Ethics Education." *Science and Engineering Ethics* 21 (2): 441–460. doi:10.1007/s11948-014-9539-7.

Hansson, S. O. 1996. "Decision Making Under Great Uncertainty." *Philosophy of the Social Sciences* 26 (3): 369–386. doi:10.1177/004839319602600304.

Hansson, S. O., and G. H. Hadorn edited by. 2016. "Logic, Argumentation & Reasoning". *The Argumentative Turn in Policy Analysis*. Vol. 10. Cham: Springer International Publishing; doi: 10.1007/978-3-319-30549-3..

Harris, C. E. 2008. "The Good Engineer: Giving Virtue Its Due in Engineering Ethics." *Science and Engineering Ethics* 14 (2): 153–164. doi:10.1007/s11948-008-9068-3.

Harris, C. E., M. Davis, M. S. Pritchard, and M. J. Rabins. 1996. "Engineering Ethics: What? Why? How? And When?." *Journal of Engineering Education* 85 (2): 93–96. doi:10.1002/j.2168-9830.1996.tb00216.x.

Harris, C. E., M. S. Pritchard, R. W. James, E. E. Englehardt, and M. J. Rabins. 2019. *Engineering Ethics: Concepts and Cases*. Sixth edition. Australia ; Boston, MA: Cengage.

Haws, D. R. 2001. "Ethics Instruction in Engineering Education: A (Mini) Meta-Analysis." *Journal of Engineering Education* 90 (2): 223–229. doi:10.1002/j.2168-9830.2001.tb00596.x.

Hess, J. L., and G. Fore. 2017. "A Systematic Literature Review of US Engineering Ethics Interventions." *Science and Engineering Ethics*. April. doi: 10.1007/s11948-017-9910-6.

Hess, J. L., S. Miller, S. Higbee, G. A. Fore, and J. Wallace. 2020. "Empathy and Ethical Becoming in Biomedical Engineering Education: A Mixed Methods Study of an Animal Tissue Harvesting Laboratory" *Australasian Journal of Engineering Education* 1–11. July. doi: 10.1080/22054952.2020.1796045.

Hillerbrand, R. 2006. *Technik, Ökologie Und Ethik*. Padeborn: Mentis.

Hillerbrand, R., and S. Roeser. 2016. "Towards a Third 'Practice Turn': An Inclusive and Empirically Informed Perspective on Risk." In *Philosophy of Technology after the Empirical Turn*, edited by P. E. Maarten Franssen, P. K. Vermaas, and A. W. M. Meijers, 145–166. Vol. 23:. Cham: Springer International Publishing. doi:10.1007/978-3-319-33717-3_9.

Hillerbrand, Rafaela. 2008. "Dianoetic Virtues in Addressing a Morally Correct Treatment of Genetic Engineering. Rafaela Hillerbrand and Rasmus Karlsson, eds. *Beyond the Global VIllage: Environmental Challenges Inspiring Global Citizenship*. 191–201. Oxford: Inter-Disciplinary Press.

Höffe, O. 1993. *Moral Als Preis Der Moderne: Ein Versuch Über Wissenschaft, Technik Und Umwelt*. Frankfurt: Suhrkamp.

Itabashi-Campbell, R., J. Gluesing, S. Perelli, and N. Oly Ndubisi. 2012. "Mindfulness and Product Failure Management: An Engineering Epistemology." *International Journal of Quality & Reliability Management* 29 (6): 642–665. doi:10.1108/02656711211245647.

Itabashi-Campbell, R., S. Perelli, and J. Gluesing. 2011. "Engineering Problem Solving and Knowledge Creation: An Epistemological Perspective". In *First International Technology Management Conference*, 777–789. San Jose, CA, USA: IEEE. doi: 10.1109/ITMC.2011.5996057.

Koehler, J., O. Pierrakos, M. Lamb, A. Demaske, C. Santos, M. D. Gross, and D. F. Brown. 2020. "What Can We Learn from Character Education? A Literature Review of Four Prominent Virtues in Engineering Education," 28.

Lempert, R., N. Nakicenovic, D. Sarewitz, and M. Schlesinger. 2004. "Characterizing Climate-Change Uncertainties for Decision-Makers. An Editorial Essay." *Climatic Change* 65 (1/2): 1–9. doi:10.1023/B:CLIM.0000037561.75281.b3.

Luckner, A. 2005. *Klugheit*. Berlin: De Grutyer.

Madhav, C. B. 2014. *"Phronesis in Defense Engineering: A Case Study in the Heroic Actions of Two Defence Engineers as They Navigate Their Careers. "* Minneapolis: University of St. Thomas.

Marcum, J. A. 2009. "The Epistemically Virtuous Clinician." *Theoretical Medicine and Bioethics* 30 (3): 249–265. doi:10.1007/s11017-009-9109-1.

Martin, M., and R. Schinzinger. 2009. *Introduction to Engineering Ethics*. New York: McGraw-Hill.

Mathwig, F. 2000. *Technikethik-Ethiktechnik: Was Leistet Angewandte Ethik?* Stuttgart: Kohlhammer.

Mintz, S. M. 1996. "Aristotelian Virtue and Business Ethics Education." *Journal of Business Ethics* 15 (8): 827–838. doi:10.1007/BF00381851.

Moriarty, G. 2009. *The Engineering Project: Its Nature, Ethics, and Promise*. University Park, PA: Pennsylvania State University Press.

Niever, M., T. Richter, K. Duehr, M. Wilmsen, L. Lanz, B. Walter, A. Albers, and C. Hahn. 2020. "KaLeP: A Holistic Case-based Action Learning Environment to Educate Successful Future Engineers." *Athens Journal of Education* 7 (3): 297–312. doi:10.30958/aje.7-3-4.

Peterson, M. 2017. *The Ethics of Technology: A Geometric Analysis of Five Moral Principles*. New York: Oxford University Press.

Peterson, M. 2019. *Ethics for Engineers*. Oxford, New York: Oxford University Press.

Pierrakos, O., M. Prentice, C. Silverglate, M. Lamb, A. Demaske, and R. Smout. 2019. "Reimagining Engineering Ethics: From Ethics Education to Character Education." In *2019 IEEE Frontiers in Education Conference (FIE)*, 1–9. Covington, KY, USA: IEEE. doi: 10.1109/FIE43999.2019.9028690.

Poe, Ibo van de. 2015. "Morally Experimenting with Nuclear Energy. Behnam Taebi and Sabine Roeser, eds. The Ethics of Nuclear Energy, 179–99. Cambridge: Cambridge University Press. https://doi.org/10.1017/CBO9781107294905.010

Poel van de, I., and L. Royakkers. 2011. *Ethics, Technology, and Engineering*. Chichester, UK: Wiley-Blackwell.

Polmear, M., A. D. Chau, and D. R. Simmons. 2020. "Ethics as an Outcome of Out-of-Class Engagement across Diverse Groups of Engineering Students" *Australasian Journal of Engineering Education* 1–13. October. doi: 10.1080/22054952.2020.1836752.

Poznic, M., M. Stacey, R. Hillerbrand, and C. Eckert. 2020. "Designing as Playing Games of Make-Believe." *Design Science* 6: e10. doi:10.1017/dsj.2020.8.

Pritchard, M. S. 2001. "Responsible Engineering: The Importance of Character and Imagination." *Science and Engineering Ethics* 7 (3): 391–402. doi:10.1007/s11948-001-0061-3.

Resnik, D. B. 2012. "Ethical Virtues in Scientific Research." *Accountability in Research* 19 (6): 329–343. doi:10.1080/08989621.2012.728908.

Rittel, H. W. J., and M. M. Webber. 1973. "Dilemmas in a General Theory of Planning." *Policy Sciences* 4 (2): 155–169. doi:10.1007/BF01405730.

Robinson, S., and R. Dixon. 1997. ""The Professional Engineer: Virtues and Learning."." *Science and Engineering Ethics* 3 (3): 339–348. doi:10.1007/s11948-997-0040-4.

Roeser, S. 2012. "Emotional Engineers: Toward Morally Responsible Design." *Science and Engineering Ethics* 18 (1): 103–115. doi:10.1007/s11948-010-9236-0.

Sand, M. 2018. "The Virtues and Vices of Innovators." *Philosophy of Management* 17 (1): 79–95. doi:10.1007/s40926-017-0055-0.

Schmidt, J. A. 2014. "Changing the Paradigm for Engineering Ethics." *Science and Engineering Ethics* 20 (4): 985–1010. doi:10.1007/s11948-013-9491-y.

Simkins, D. W., and C. Steinkuehler. 2008. "Critical Ethical Reasoning and Role-Play." *Games and Culture* 3 (3–4): 333–355. doi:10.1177/1555412008317313.

Steinert, S., and S. Roeser. 2020. "Emotions, Values and Technology: Illuminating the Blind Spots" *Journal of Responsible Innovation* 1–22. April. doi: 10.1080/23299460.2020.1738024.

Vallor, S. 2016. *Technology and the Virtues: A Philosophical Guide to A Future Worth Wanting*. New York, NY: Oxford University Press.

Whitbeck, C. 2011. *Ethics in Engineering Practice and Research*. Second edition. Cambridge: Cambridge University Press.

Zagzebski, L. T. 1996. *Virtues of the Mind: An Inquiry into the Nature of Virtue and the Ethical Foundations of Knowledge*. New York, NY, USA: Cambridge University Press.