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REIMAGINING THE FUTURE OF ENGINEERING

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Reimagining suggests the idea of opening up new, unconventional spaces of possibilities for an activity or an entity that already exists. At its most transformative, the activity of reimagining develops spaces of possibilities that alter the very definition of that activity or entity. What, then, would it be to reimagine the future of engineering?

An exploration of such a topic cannot be done well by a single individual but rather requires the combined perspectives and insights of a number of people. The thoughts presented in this chapter had their beginnings in a workshop on this topic which took place at a meeting of the Forum on Philosophy, Engineering and Technology (fPET) at the University of Maryland, College Park, in 2018. Because participants in the workshop came from the fPET community, they included philosophers and engineers from both inside and outside the academy. On this account, reimagining the future of engineering is a matter of reimagining and redrawing the spaces of engineering itself: spaces for designing, action, problem framing, professional and disciplinary identity, and for the training of future engineers.

55.1. The Virtuality of Future Engineering

A concrete example of one new space in engineering is digital space. Digital technology permeates engineering work, just as it does all parts of human life. In cyber-physical architectures, digital representations are closely associated with the physical systems to which they refer, such that both are treated as a unity. Comprehensive simulations are used to support the design of such systems, which provide digital representations of physical phenomena that include user behavior to get to know the workings of engineered systems. All this has given engineers better access to the subject matter of their work, but it has also changed the points of orientation that help them find direction in their activities. Digital models allow for new types of benchmarks in the ideation, design, and evaluation of engineering products. So, apart from the extended affordances digitalization may provide to products of engineering, it fundamentally changes the engineering process.

Epistemological and normative implications of digitalization for the engineering process are extensively explored in many different domains. What remains unclear is whether digitalization also changes the notion of engineering in its core. At first glance, it would seem to be the opposite. For a long time, engineering has been related to the application of abstract mathematical methods to designing, building, creating, operating, and maintaining engineering products and systems, e.g. in the specification of the general desiderata for an end product into operationalizable requirements and measurable goals. The use of digital technology goes along with a formalization of the subject matter, which relates practice even more than before to symbolic representations such as models and constructs. This makes digitalization fit very well into already-existing approaches to engineering. Moreover, it might explain why the digital transformation is strongly embraced by so many engineers: it fulfills the wildest dreams about changing the world by systematic design, enframed in symbolic structures of interrelated and controllable objects and properties. One could therefore argue that digital technology makes current practices of engineering more powerful as it grants access to any field of human experience through bits and bytes. Doesn't that strengthen the position of engineering as it is, underlining its leading force in progress and development?

At the same time, however, one could put forward an argument pointing in the opposite direction: in expanding its scope to comprehensive representations of the lifeworld, engineering cannot stay as it is. As the contribution of engineering to the solution of human problems changes, the foundations of its operative principles need a careful review to redefine its role in society.

Support for this argument can be taken from simple combinatorial considerations of the size of the design spaces which digital technology opens up for engineering. Digital technology has increased the range of options for engineering design in so many different directions that the fixed points of reference that have so far given orientation and direction disappear, creating the need for the choice of artificial replacements which give the design space a completely new texture.

The automotive industry is one domain where the changing conceptions of engineering under the influence of digitalization can clearly be seen (e.g. Kirk 2015; Hars 2015; Gusikhin et al. 2007). Auto manufacturers are turning into IT companies and data brokers who do not primarily take physical improvements in materials, mechanics, or aerodynamics as drivers of innovation, but IT. More and more layers of IT are created between users and the effects of their actions in the physical world, as well as between auto mechanics and the car as a physical object.

Going a step further, controls and displays in automobiles themselves are already mostly digitally operated, even if the driver does not perceive it. Analog displays (if still existing) are superficial, and behind them is digital data; the resistance of the brake and gas pedal is also created artificially, as there is no physical connection to other parts of the car, just a digital recognition of the signals created by the driver which are sent to the respective automotive controls.

Digitalization also shows up in the process of automotive design. The techniques for shaping and making automotive parts are in their own way also cyber-physicalized via additive manufacturing. It gives endless opportunities to create new parts with properties never seen before based on digital designs, making them lighter and better resistant to pressure and heat, and allows changing aesthetics.

Beyond the engineering products and processes, digitalization impacts the business logic behind automotive engineering, driving innovation in unexpected directions. New profit margins are created by assistance systems (parking, navigation, accident prevention) and service provisions enhancing the driving experience without being related to motion in space at all (entertainment systems, telematics insurance schemes, car sharing, and mobility solutions). Add to that the potential of reusing the data gathered in the use of such services, giving those data exploitable value, and we can see how other models of the functionality of the car emerge in larger economic structures.

Like the smartphone, the car has become its own kind of platform onto which many different aspects of the user's life can be linked. Whereas the smartphone is carried close to one's skin and taken everywhere, the car creates a sphere of intimacy where we are nurtured by technology. This does not require the classical strengths of automotive engineering: powerful engines, smooth riding, and full control.

All this gives the impression that the car as an object of engineering, although remaining present in a physical embodiment, becomes virtual in different ways. The experience of driving is simulated, while the mechanics and parts of the control happen behind the user interface, both inside the car and beyond it. Also, the actual instance of the car loses importance, as is demonstrated, for example, by how car-sharing, etc., provide mobility-as-a-service, where the material objects are totally replaceable. And with the services it uses from outside, by being with connected, and with continuous updates on controls and displays, the car as an engineering product extends beyond its former spatial and temporal limits.

Digital representations thus become the predominant subject matter of engineering with endless new possibilities to be divided into pieces and set together again in a new way. This has consequences for the design space: it practically explodes to form a whole new universe. Furthermore, even the notion of a singular artifact itself becomes blurred: In the case of the car, one does not know exactly where its design space ends and the design space of one of the other objects (interconnected devices, cameras, traffic control, insurance) starts. Formerly discrete design spaces become inherently related, creating additional degrees of freedom for engineering.

This explosion of engineering design space in endless and often opaque options for future development has consequently a radical impact that needs to be addressed on operative-practical, epistemic, and ethical levels. Who in this design space can be said to be designers? Can engineers continue to be seen as the "authors" of artifacts? When (if ever) do we consider an engineering product a finished artifact? What is the artifact's function or the problem that it solves? In addition, as basic needs are increasingly satisfied, technological innovation will take on an increasingly totemic flavor, and engineers who work in areas that most appeal to rapidly changing consumer preferences will increasingly find themselves working on curiosities for consumerist consumption. How will this change the engineer, who is, at least in a nominal sense, a problem-solver interested in the benefit of humankind? Will the engineer, by and large, participate in this self-referential dynamic of technological innovation for the sake of technological innovation? To what extent will this participation be conscious? How will the profession define itself? Even engineers who "remain behind" to work on fundamental problems will find challenges, as they discover that the technical contribution to the solution pales in comparison to the contributions of public policy and other fields. How will the engineer and the profession respond as the innovative aspects of engineering work fade in importance or become subsumed by meaningless consumption?

These questions indicate that there is yet another design process to be addressed, since it does not seem possible to answer them convincingly based on mere factual information. With its expansion through digital technology, engineering itself becomes the subject of a design process.

55.2. The Self-Awareness of Future Engineers

Another example of a new kind of space within which modern engineering operates is the space of open systems, where design and research problems exist within social and political contexts. In open systems, engineering is more about framing problems and viewing the solution space in different ways than "solving" the problem or finding *the* solution. Open system problems are typified by the Millennium Development Goals, UN Sustainable Development Goals, or the notion of a "grand challenge" or "wicked problem".

This space is connected to an emerging ("new") self-awareness in the modern engineering community and in the community at large. The "problem" (agenda) of engineering is (traditionally) the problem of design. Herbert Simon characterized engineering design problem-solving as attempting to move from a current state of affairs to a future, more desirable state of affairs. By being perhaps a definitional tautology of all problem-solving, Simon's characterization will also apply to the work of the future engineers. But unlike the older imagined, value-neutral scientific spectator on reality, the future engineer is an embodied and active participant in the historical emergence of reality and possesses a value agenda. The engineer of the future will be more attuned to how engineering design fits within this emergence where values, materiality, culture, and politics are inseparably interconnected.

From here, engineers will be naturally led to design not just technical solutions, but many possible solutions reflecting different values and valuation. Samuel Florman pointed out that we are naturally creative "existential" engineers in that we are embodied with the ability to act in the world, but, in important ways, without a defining script (i.e., inherent uncertainty) (Florman 1994 [1976]). We are not "scientifically determined". Rather, we are constrained with an irreducible component of creative freedom. We each choose how to design our lives—e.g., how much time to spend with family, how much time to spend at work. And we are all naturally concerned with how to treat/relate to others as well as, self-reflexively, ourselves. This points to the idea that engineering is about the development of how we should live. And "how we should live" is the defining question of morality. Here, one might claim that the fundamental framework of engineering is concerned with morality.

With the new, general conception of engineering as a moral framework, engineering would reunify the idealized "scientific" and "humanities" cultures (Grasso and Burkins 2010; Petroski 2016). The engineer of the future asks "*for whom* are we designing and *how can* this be designed?" How such an engineer approaches or responds to those fundamental questions will be influenced by a number of factors: personal values, professional values, societal values, education and experience, position and authority, etc. In order to consider possible responses, and based on a common practice in engineering as a means of exploring a problem-solution space, the following section proposes some scenarios and uses them as a lens to look at the question of *who* an engineer is. The personas presented, and the virtues or vices that define them,[1] may typify different engineering practitioners or researchers in future scenarios connected to open system spaces.

55.3. The Personas of Future Engineers

Addressing tasks and problems in open systems will strengthen the requirement that engineers will work in teams (with other engineers and non-engineers) when taking up projects. This raises the question of what roles engineers can take up in these teams. We discern several possibilities in terms of personas that are not mutually exclusive: an engineer may take up a role characterized by two or more personas. These personas are simplified descriptions of aspects of real-life engineers' personalities. Furthermore, the personas are intertwined with moral and epistemic virtues of engineers understood as relatively stable character traits. The virtues reflect the general values of engineering such as collaboration and teamwork as well as efficient problem-solving. In the following, we will propose an ordering of personas along the two analytic dimensions of systems orientation and openness to society.

The first persona concerns the existing role of engineers to deliver expert knowledge and skills about technology and design to a project. This persona of *technology expert* ignores the emergence of open systems and their societal aspects. This persona is inclined to leave choices about developing systems and bringing in societal considerations to other team members. The technology expert needs to develop epistemic virtues such as open-mindedness and creativity but may lack important moral virtues such as empathy and care.

Two other personas do address the system character of open systems but might not take the societal aspects on board. The *systems expert* brings in expertise about systems design. This persona is still subservient on the team but takes up broader responsibility to implement changes and developments. The *moderator* takes up a coordinating role on the team by using systems expertise to align the work of team members and stakeholders and translate it into opportunities for and developments of engineering systems. These two personas embody central moral and epistemic virtues that are important traits of any good, responsible engineer.

Still, in these two scenarios, all is not "business as usual". For instance, the moderator shows the virtues of humility and empathy and thereby is already more open to society by also being oriented to stakeholders as clients, users, and others involved or affected by a project. This openness is central to two further personas. The *social engineer* is committed to issues in society such as the UN Sustainable Development Goals and initiates and participates in projects to address them. The *visionary* is focused on society as well, not on specific issues but by envisaging innovative ways to address existing or future aims. Creativity is a virtue especially relevant to the visionary engineer; it can be said to be *the* character trait of engineers that embody a visionary persona. In general, the social and visionary engineer both take up responsibility, as do the systems expert and moderator, but in their best implementation they also display the virtues of justice and wisdom.

Two more personas, already becoming visible today and likely to remain so in the future, stand somewhat outside the sequence of the five described so far. These personas are characterized by certain vices rather than virtues. The first is the *disrupter*. Addressing tasks and problems in open systems may require overhauling current technologies, infrastructures, and societal arrangements, and for this a more disruptive approach can be chosen by hacking systems and by introducing game changers. In this manner, vices such as negligence and carelessness may become apparent. The second persona is the one of the *compromised engineer* whose contributions to tasks and problems are eventually assessed as unprofessional, unethical, or illegal. In the language of virtues and vices, one may call such a persona the "vicious" engineer who acts irresponsibly as, for example, was seen in the cases of the Volkswagen emissions scandal or the Cambridge Analytica incident. Vices of moral and epistemic injustice may be further character traits possessed by a compromised engineer.

As said, these personas are not mutually exclusive, and they are not descriptions of real-life persons. For instance, the visionary engineer is typically one who thinks in terms of technological possibilities. The engineer who moderates in a team can do so by taking a systemic perspective on the team's project. And the engineer who ends up into a compromised position can have gotten there through a series of virtuous contributions to regular technological developments within teams.

55.4. Implications for Future Engineering Education

This section presents a reflection on the implications for engineering education—*how should* we "design" engineers, and *for whom* are we designing the engineering education system?

Idealistically (and at the risk of being reductive), engineering is problem-oriented. It takes up challenges with a range of complexity and moral weight (i.e., creating a means of transport across this body of water, improving the well-being and comfort of a patient, etc.), and seeks to provide practical, workable, and often innovative solutions. Many of the problems that we see emerging, and that will in all likelihood continue to define the 21st century, are large, complex, systemic, multifaceted, etc. As already mentioned, these are often referred to as "wicked problems" or, more recently, "grand challenges". A paradigmatic example would be climate change, which has far-reaching social, political, and technical causes and ramifications.

As modern engineering practice shifts from contained, well-defined technological challenges to open, ambiguous societal challenges, an "engineer" becomes a broader label. In the exploration just given, the notion of "engineer" as a one-size-fits-all label built upon a fixed body of disciplinary knowledge and professional identity receded, and multiple scenarios (or personas) that reflect future engineers' different roles, values, and relationships with the sciences, humanities, and society came into view. Rather than offering a definitive answer to the question "Who is an engineer?" a multidimensional framing of a diverse engineering profession was presented.

Instead of defining engineers by what they "do" or "know", the engineering profession in the future will be defined by who engineers are as people. What characters and cultures do people who do engineering represent? In 2015, a social media and marketing campaign using #ILookLikeAnEngineer presented a wider view for the public of who is an engineer and what engineers do, beyond the typical stereotypes and buzzword industries (Guynn 2015). The types of people who do engineering in an open-space problem environment is broader than the traditional 20th-century engineering stereotype of someone who applies math and science to solve a problem. Perhaps an engineer is someone who uses engineering tools, processes, and mindsets to move from a current state to a better state. Or perhaps engineers will be defined by their character and striving for virtues, both ethical (e.g., honesty, courage) and epistemic (e.g., wisdom, creativity).

This way of thinking suggests moving beyond defining engineers by their disciplinary body of knowledge, which is common with professional organizations, licensure, and college accreditation. It might, for example, suggest a reorientation and reorganization of engineering, from sub-disciplines to challenges (i.e. a climate change engineer instead of a civil or aerospace engineer, etc.).

Would such a reorientation be more effective in addressing and solving grand challenges like climate change? What is the "minimum" or "shared" knowledge and skills across engineering disciplines? (Vincenti 1990). Does it differ by career track? Is education more about ways of thinking and doing than specific knowledge and skills? (cf. Neely et al. 2018). "Engineer" already refers to diverse people and roles, and so engineering education in the future will need to reflect more diverse ways of learning and evaluating success. If engineering education is to remain relevant in the future, it needs to adapt and educate the whole person. Based on the scenarios, an engineer is defined by knowledge/skills, processes, relationships, character, and worldview. Thus, engineering education and training should also focus on the whole person.

In the future, will engineering graduates identify as engineers, and will they find pleasure in the work of engineering? Perhaps the answer primarily depends on whether engineers find themselves in the right engineering track to address the societal challenges that matter to them.

55.5. Future Spaces of Engineering Responsibility

Questions of social, moral, and legal responsibility permeate the philosophy and ethics of engineering (including presentations at fPET). Responsibility is a key issue in engineering ethics education, and foundational to well-established theoretical topics such as risk. And, responsibility (broadly conceived) is an underlying foundation for more recent developments in philosophy of technology, such as value-sensitive design, responsible research and innovation, and questions of agency in postphenomenology/mediation theory. Thus, what seems undeniable is that engineers—and engineering as a whole—carry a heavy burden of responsibility. Yet this burden also creates new opportunities, for finding creative, innovative, and workable solutions is then also the responsibility of engineering. Importantly, it raises questions of how to (continue to) take ownership of this "responsibility for responsibility" and further incorporate it into the demarcated *moral* (not just legal) space of engineers and their toolbox. This also requires new approaches to engineering ethics education.

55.6. New Approaches to Case Studies

Historically, case studies have been a valued component of engineering ethics education. For instance, in their textbook *Engineering Ethics*, Charles Harris, Michael Pritchard, and Michael Rabins state that "the importance (of cases) cannot be overemphasized. It is by studying cases that a person can most easily develop the abilities necessary to engage in preventive ethics" (Harris et al. 1995; p. 12). Indeed, well-designed cases can enable students to see how engineering design is embedded within a complex framework of cultural, ethical, political, financial, and social factors. If, however, this complex framework remains *simply* as the unreflected-upon context for a case study, the study fails to capture important lessons for engineering education. In this regard, Donna Riley and Yanna Lambrinidou take this criticism even further (Riley and Lambrinidou 2015), worrying that the typical focus of case studies on "micro-ethical dilemmas" serves to do more harm than good by obscuring and rendering invisible the larger social and structural contexts which are the real root of the dilemmas in the first place. Without speaking of personas *per se*, they also make the point that the case study approach often gives the persona of *technological experts* (the first persona mentioned earlier) to the engineers involved. This effectively legitimizes the boundary between engineering understanding and the understandings of the publics affected by the decisions of engineers. For instance, in a case study examining the devastating 2010 earthquake in Haiti and considering what engineers should do looking forward as Haiti is rebuilt, Charles Fleddermann (2012: 117) emphasizes the need to use "state-of-the-art earthquake resistant design" and (in the case of engineers from outside Haiti) to "help support Haitian engineers in learning appropriate design and construction techniques", without giving consideration to public input and perhaps looking to rectify injustices perpetrated by existing institutions.

Another difficulty with using case studies to teach engineering ethics is that students may be left with the impression that ethical challenges are easy to identify, that there is always a "smoking gun", or that the ethical problems should be left to the ethical experts (and not engineers). If students are not adequately engaged, they may leave the discussions about ethics without having developed their own abilities to identify and examine novel problems in engineering in their full sociohistorical context. In addition, when faculty select cases, they may be tempted to pick ones that are canonical and much discussed already, and so replicate the persona of the *technological expert* within the classroom, inhibiting the process of discovery in their students.

One approach to consider in mitigating these challenges is to have students themselves identify current cases relevant to their discipline for which there is not yet an authoritative "right" answer to the ethical problems. Allowing students to work through the messiness of a case, perhaps over the length of an entire course, could help them develop valuable competencies for identifying, examining, and addressing ethical issues.

55.7. Dealing With the Hidden Curriculum

A focus of the previous section was the often-hidden context of case studies. We turn now to another challenge of integrating ethics more effectively into engineering curricula, namely, the "hidden curriculum". For Van de Poel et al. (2001: 278), the "hidden curriculum" of engineering studies is largely tied to attitudes that students acquire informally in the course of their program which "leads to an a priori skeptical attitude on the part of engineering students towards 'soft' disciplines like ethics". For instance, students may experience a disparity between explicit claims about the importance of ethics and the reality in which ethical implications of student projects are considered to lie beyond the scope of engineering. The formation of the "hidden curriculum" may also be seen as a matter not only of attitudes but also personal epistemologies which contribute to the belief that ethics is "a matter of personal opinion". As Tormey et al. (2015) suggest, if students' first encounters with engineering involve a strong focus on fundamental, agreed-upon scientific principles, they may end up unconsciously adopting a personal epistemology which "may lead students to come to see problems which do not have a single correct answer as being 'simply a matter of opinion' rather than an opportunity to engage in a different way of constructing their understanding of the world" (Tormey et al. 2015: 4). This personal epistemology can also feed into and reinforce a formal classroom emphasis on producing artifacts that work rather than reflecting on the ethical implications of the artifacts to be created (Tormey et al. 2015; Van de Poel et al. 2001).

Any effort at reimagining the future of engineering ethics education needs to directly open up educational spaces in order to confront this hidden curriculum. Educators need to carefully consider the messages that they may unintentionally be sending about the value of ethics and professionalism while designing their pedagogical approaches, and maybe even discuss the very existence of this hidden curriculum. A potential benefit of revealing the hidden curriculum to students is that it can encourage them to critically analyze the social institutions in which they are embedded. This may make students less likely to simply accept workplace norms that are ethically dubious once they join the profession.

55.8. Concluding Thoughts

By design, the thoughts presented here are inconclusive. They take up and address the question of reimagining the future of engineering, but are far from giving the question a definitive answer. Pitt and Shew (2017) have turned to the idea of "space"—specifically ethical, political, virtual, personal, and inner and outer space—as a way of organizing the areas within which philosophers of technology now and in the future will be likely to work. The word "space" figures prominently in the thoughts presented in this chapter as well, as a device for exploring how the spaces of engineering might be reconfigured. We have deliberately not given any indication of how the spaces highlighted here might be prioritized or ordered. For instance, one might naturally think that reimagining the future of engineering is fundamentally grounded in reimagining the future of engineering education. However, the space for changing engineering education is also dependent on the space provided by society for making such a change. Likewise, the various engineering personas presented in this chapter are not just a matter of engineers assuming these roles but also of society allowing engineers to adopt them. We hope the reader will see the inconclusiveness of this chapter as a virtue rather than a negative characteristic and that it will serve to inspire future dialogue between philosophers and engineers.

Note

1. Preliminary discussion of the scenarios and personas presented here took place in a subgroup at the fPET 2018 workshop.

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