Complexity, Right Action, and the Engineering Curriculum

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Abstract

Today's engineering students face a very different world than their predecessors. As engineering has adapted to a more global and interconnected economy, the issues that face today's engineers have become more complex. In a highly networked world notions of the impact of an engineer's actions on others, the basis for moral and ethical behavior, also become more complex. The definition of complex used here captures higher-order and emergent behaviors, situations that can change rapidly, limitations to predictability, and behavior arising from interactions rather than innate to components. While ethics has remained central to engineering education and in general has retained its deontological basis, this paper questions whether the basis for engineering ethics has changed over time and can be expected to change in the future. The fact that the future ethical challenges engineering students will face will be distributed and complex while most engineering curricula focus on simplified systems and decisions indicates emerging challenges for effectively addressing engineering ethics within the curriculum.

Frameworks that distinguish simple and complicated from complex systems—in which outcomes are more uncertain—emphasize that action becomes more important than knowledge. In other words, it is more important to do what is right, even if one's actions are imperfect, than know what is right to do. This paper explores the intersection of engineering curricula and engineering ethics from the perspective of "right action", that is being able in act in ways that lead to moral outcomes. It is argued that by focusing predominately on knowledge and situating learning in academic settings engineering curricula miss opportunities for developing capabilities for action. Through this lens the opportunities to address engineering ethics in the curriculum are seen to lie predominately outside traditional coursework.

Introduction

This short query into acting as an engineer seeks to explore the question of the limits of engineering ethics as it is currently taught in undergraduate engineering programs. In particular are there situations where engineering students are not prepared by current pedagogies to act ethically? To frame this question this paper questions how well rules-based, or deontological, ethics provides useful guidelines in the case that the domain in which decisions are made become complex or when technology is changing rapidly. Given that some companies report the half-life of information is as short as six months [private communication], can engineering ethics always provide useful guidance to action, or are there situations where other ethical frameworks are more appropriate?

Engineering ethics is an often-discussed subject, and substantial work in engineering education addresses how to effectively teach ethics [1]–[3], evaluate learning outcomes [4], and identify issues and tensions inherent to teaching ethics [5]. Since the number of ethical dilemmas is infinite, it is not surprising that the body of knowledge of engineering ethics is also vast. The question then is not is there a "right" way for engineers to learn ethics, but what form of learning best prepares them to act ethically as an engineer? Despite the large number of topics and techniques to cover ethics in a curriculum, there are many commonalities to how most engineering degree programs teach ethics. In order to learn to act ethically as an engineer students typically apply agent-centered deontological, or duty-based, codes of ethics adopted by engineering societies. Such codes of ethics place specific obligations on engineers, often putting serving the public welfare first with service to clients, employers, and the profession secondary. Another common method for teaching ethics are the use of case studies which highlight the decisions engineers made to real-world crises or disasters so that students can disentangle difficult decision-making processes [6].

Such case studies work well for deontological ethics since moral or right behavior is related to the intention of the agent [7]. However when one looks more deeply at intention, ethical decisions are also based on the underlying belief systems of what is good, or moral framework, that students hold [8]. This is an important but potentially problematic aspect of teaching ethics since the pathways of engineering students—both entering and leaving degree programs—are many and varied [9], [10]. Ethics, which for engineering consists of standards of professional behavior that apply to engineers as a group, differs from morality, which is personal and normative. Making ethical decisions is, however, based on a person's moral stance since in serving public welfare engineers must have some sort of mental framework to make assumptions about what is good or serves public welfare. Traditionally moral codes are assumed to be well developed by the time a student enters college [11], however since programs increasingly draw students from diverse backgrounds who are then further fragmented into affinity groups [12], having well developed moral codes, particularly shared codes, may today be a questionable assumption. The reason that morals matter when it comes to teaching engineering ethics is that there is not universal agreement on how act for good when students hold diverse sets of beliefs. Neoliberalism, free market capitalism, socialism, populism, and nationalism are ideologies which may lead to widely different judgements about how to act to serve the public welfare [13], particularly in the realm of macro-ethics [14]. By emphasizing professional ethics rather than moral good engineering sidesteps many ideologically fraught questions of right and wrong, allowing engineers to be ideologically agnostic. While perhaps such a stance is beneficial for the engineering profession and its role in maintaining public infrastructures, never-the-less students need to learn how to navigate different belief systems since these certainly exist outside the university. As Newman argues, one of the ideas underlying a university is to provide a forum for students to refine these belief systems [15] through fellowship with their peers.

Another argument for the limits of engineering ethics as currently taught is the increasing recognition that technological decisions in areas of care and artificial intelligence have on individual lives [16], [17]. For example recent studies have found that those who are lonely or have weak social ties suffer significant negative health effects, that being socially disconnected causes more harm that air pollution or physical inactivity [18], and that over a fifth of adults in the US and the UK report being lonely most of the time [19]. Given that the National Society of Professional Engineer's code of ethics states that "*Engineers in the fulfillment of their professional duties, shall: 1) Hold paramount the safety, health, and welfare of the public. 2) Perform services only in areas of their competence…*" it is worth asking if loneliness falls within the domain of public welfare? In an age in which technology is augmenting or replacing face-to-face contacts the bounds of public welfare become tenuous and human concerns begin to encroach in engineers' areas of competence. This question seems even more pressing since recent studies show that engineering degree programs cause students' concern for public welfare to decline slightly over their time in college [20].

Simple, Complicated, and Complex

Another way to frame the question of what aspects of ethics education will best serve future engineers is by the type of problems engineers work on, or how to categorize the domains of practice engineers work in. Here we utilize the Cynefin framework [21] to classify problems or systems on four domains: simple, complicated, complex, or chaotic. The Cynefin framework hypothesizes that what defines effective action or an individual's ability to navigate a situation is domain dependent. The simple/obvious domain represents the domain of well understood problems that lie within an engineer's expertise. There are well defined rules or best practices and the problems the engineer works on do not change with time, at least on the time-scale in which the work occurs. For simple systems the relationship between cause and effect is clear and proper actions are to "sense–categorize–respond": (1) establish the facts (sense), (2) figure which well understood rules or theories apply (categorize), (3) then take action by applying the rule or theory (respond). Undergraduate problems are often reduced to the simple domain since such procedures once learned are easy to work with and in; as Kahnemann points out our minds are lazy [22]. The simple domain is where engineering likes to shift problems through techniques of decomposition so processes can be simplified to standard operating procedures; thus decision-making reduces to finding the proper rule and applying it.

The complicated domain occurs in activities such as building a system which has multiple parts or subsystems that have to work together. Many larger engineering problems occur in this domain, and the relationship between cause and effect requires analysis or expertise since there can be a range of acceptable answers. Because of the number of possible solutions the Cynefin framework recommends a "sense–analyze–respond" approach where an engineer tries to: (1) see the whole system and its parts (sense), (2) explore the facts as they understand them (analyze), then (3) from their expertise apply the most appropriate solution (respond). In this domain it is possible to work toward a solution using the judgment and expertise that engineering degree programs seek to develop. Much of our conversation in engineering education is about how to get our students to develop the expertise to manage works in this domain through projects, design, etc. These types of problems are increasingly amenable to AI solutions.

Working in the complex domain relies on different mental rules than the simple and complex domains. The reason for this is that problems or systems which can be characterized as complex exhibit behaviors not shared by simple and complicated system. While not an exhaustive list, complex systems exhibit the following characteristics:

- Emergence: Out of the interactions between the individual elements in the systems behavior emerges at the level of the system as a whole. Such higher order behavior isn't a function of the parts of the system as it would be in a complicated system. Rather emergence creates behaviors that extend beyond what any one of the parts is capable of; the whole is more than the sum of its parts.

- Sudden transitions / tipping-points / non-linearity: Complex systems show non-linear dynamics which means that they may suddenly change their behavior or move to another regime of behavior. They can also move from a high degree of stability to very unstable behavior in relative short periods of time, e.g. revolutions and financial crises.
- Limited predictability: Because of these nonlinearities the behavior of complex systems cannot be predicted well and small changes in initial conditions or history can lead to very different dynamics over time. The future of complex systems is fundamentally uncertain.
- Large changes from small inputs: Another result of nonlinearity is that relatively small changes to system inputs may lead to large effects, which occurs if a complex system is close to a tipping point. Such behavior is a result of the inter-connectivity of complex systems.
- Memory: Complex systems have memory, not located at a specific place, but distributed throughout the system. Any complex system thus has a history, and the history is of cardinal importance to the behavior of the system.
- Behavior determined by interactions: The behavior of the system is determined by the nature of the interactions, not by what is contained within the components.
- Adaptive and Self-Organized: Complex systems are adaptive. They can (re)organize their internal structure without external intervention and thus operate without central control. Such organization typically occurs from the bottom-up.

In essence in a complex situation cause and effect only become clear in retrospect (if ever) and there are no unequivocal answers, unlike simple and, to some extent, complicated systems. The complex domain is typically one of systems which involve frequent human intervention or dynamic social phenomena. While rules and expertise help an individual cope with simple and complicated systems, they can actually be a hindrance in the complex domain because the problems change dynamically. In the complex domain what matters more is preparation and the ability to follow heuristics [23] that allow individuals to take iterative action and adjust their strategy as they receive feedback. In other words, an actor conducts continual experiments that are safe to fail so that they are always sensing the environment. The Cynefin framework characterizes this process as "probe–sense–respond" and which is based more on general heuristics that hard and fast rules. Some examples are battlefields (US Marines have the heuristic keep moving, seek the high ground, stay in touch), stock markets, and organizational cultures.

In terms of belief systems or philosophies the simple and complicated domains align with rationalist and empiricist ways of seeing the world [24] which are very familiar to engineering educators. Complexity, however, aligns with a set of philosophies known as interobjectivity and intersubjectivity that an individual makes sense of the world through relationships mediated by and through objects or the environment. Little teaching in engineering science is based on such philosophical frameworks, except in the space of design.

We claim that issues with respect to teaching engineering ethics can arise when students apply the modes of thinking appropriate for one domain to a problem that is in a different domain. For example, in simple systems the best practice is, by definition, "what worked in the past should work now" but this approach can get one in trouble if they're working in complex systems. The different ways of acting identified by the Cynefin framework directly impact upon how engineering ethics is taught since many programs teach that acting rightly is determined by reference to a defined code of ethics which students can learn. From this perspective case studies are a well-established method to introduce students to ethical dilemmas because they illustrate decision making processes and applications of ethical codes. If, however case studies or other methods of teaching engineering ethics do not support the development of ethical judgement in simple situations they certainly won't in complex situations.

A Personal Framework for Engineering Ethics

A key question is whether the increasing connection between people, cultures, nations, etc. which give rise to complex behaviors require new ways of thinking about ethical questions or whether the existing deontological frameworks suffice? In other words if engineering problems increasingly cross into the domain which has aspects of complexity, as this paper and others [25] argue, then rules-based ethics becomes less appropriate to inform action. One argument for this perspective is that complexity by its nature continually reveals new configurations and the backwards-looking rules and case studies used in most engineering ethics courses provide a limited preparation to students. A counter-argument is that rules and an unchanging framework provide order to such complex environments by framing human welfare as the primary good.

Others have made the case for changing the frameworks by which engineers are trained to consider ethical issues. In particular Bowen [1] argues for an aspirational ethic that "places people over technical ingenuity for its own sake". The question of whether a personal or humanist framework is relevant in complex engineering macroethics will be discussed subsequently. Similarly Cruz, Moreno, and Howell [26] argue that ethics requires a new pedagogical framework and derive one on the basis of developments in cognitive neuroscience: "*The hypothesis of this proposal is that ethical training requires the construction of neural pathways, or networks, within the student's brain through effective pedagogical mediations and if a change in the student's neurobiological structure is not achieved, ethical behaviors are not modified*". Walker [27] suggests that current approaches to ethical education based on rationalism are insufficient because they do not take into account psychological and social factors which is similar to the argument of complex socio-technical systems made here. Other work looks at the role emotion and intuition play in ethical decision making [28]. The classic work of Perry and King and Kitchener supports frameworks where both intellectual and moral development occur over time based on the types of experiences and interactions students have with peers, faculty, and their environment [29], [30]. In these frameworks moral development moves an individual from a dualistic view of issues, through relativism, and eventually to a nuanced and critical understanding.

The above efforts align with a framework known as enactivism. Enactivisism views human existence as being strongly coupling to the physical and social worlds, which reflect interobjective and intersubjective philosophical systems [24]. Such coupling of humans to their environment introduces moral and ethical questions about autonomy and socially distributed responsibility [31]–[33]. This view sees ethics as a form of enacted wisdom: "*…we acquire our ethical behavior in much the same way we acquire all other modes of behavior: they become transparent to us as we grow up in society. This is because learning is, as we know, circular: we learn what we are supposed be in order to be accepted as learners…when the matter is viewed in this light, it is clear than an ethical expert is nothing more or less than a full participant in a community…*" [34].

From this perspective developing as an ethical engineer is to be accepted into a community that makes clear how to act rightly, and developing as a person in the community. While there are many frameworks that describe how individuals develop as persons, here we use one developed by the Scottish Philosopher John Macmurray [35], [36]. This framework has been developed elsewhere and only is briefly discussed here. In Macmurray's conception student development occurs over time by taking action through the iterative cycle shown in Figure 1. A person has an intention to act, anticipates the results of possible actions, then chooses to act in a particular way. Their choice determines what they pay attention to following the action. To make sense of the results of their action, at least the ones they paid attention to, they develop mental representations or perspectives of the result of the action. There are many possible perspectives that can be developed based on the actor's attention and interests. Regardless of how they interpret the results of their own actions, they leave the field of action with new knowledge which informs future intentions, thus starting the cycle again. Thus in Macmurray's system one's interaction with, or coupling to, the world is defined iteratively through action that is reflectively informed by knowledge gained through one's prior actions.

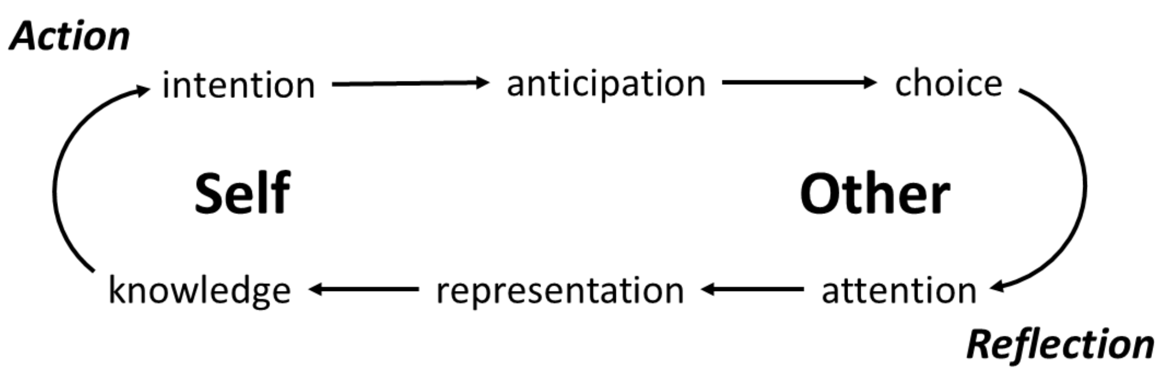

Figure 1: Macmurray's cycle of iterative action which serves to inform individuals of right actions.

We learn to act ethically through continually going through this cycle of action and reflection in a social fabric that consists of other actors. It is the feedback from these other actors, our peers and mentors, that serves to develop ethical habits. We become who we are through action, but to learn to act ethically we must act authentically, that is being ourselves rather than hiding ourselves in fear of what others may think. We learn by developing habits which let us react in the moment. If we are fortunate enough to address the types of problems in our school that we will encounter in our profession we gain wisdom and the ability to act well in the moment. This capacity for acting rightly comes not from due rational consideration, because with real ethical dilemmas we rarely have time to reflect, but from habituated awareness. If instead we limit ourselves to learning rules without the ability to practice (rather than merely read about) applying these rules the enactivist framework indicates that it is unlikely we will act for good. To be able to contribute to good we must choose to live as if our actions continually remake the world rather than where we stand aside from it and learn from the actions of others. As Varela's enactivist essays on ethical know-how point out [34], the best actions and highest virtues arise from assiduously practicing the habits that allow a person to act both wisely and spontaneously in the moment.

Unanswered Questions and (Un)Necessary Complications

One criticism of the enactivist framework is that when we are not an expert it is hard to know what right actions are. In such cases deontological ethics, drawn from Kant's moral imperative, provide sets of useful heuristics and case studies can serve as working examples on how to apply such rules. "This is all well and good," an enactivist would respond, "but without the ability to apply these rules in a way that is personally meaningful they may not provide practical guidance."

Furthermore if frameworks like Cynefin are correct and the effectiveness of actions depends on context, then learning ethical codes in one context may lead to wrong action in another. In other words a student goes through the iterative action cycle of Figure 1, but the cycle takes place in an environment that addresses simple or complicated problems. In this case the feedback the student gets may be ethical on the micro scale but support wrong action in systemic and complex scenarios. Alternatively what happens if learning occurs in an environment where what is taught as right action in fact causes harm? In such cases how does the cyclical development model lead to moral action? An example which over-simplifies a highly complex problem is the question of whether or not it right to teach students how to extract fossil fuels today?

One solution would be to have a moral expert to provide guidance to learners, which is putatively the role of faculty in a university program: to be experts, profess knowledge. Historically this has been the role of faculty within a discipline, to teach only in areas in which they profess knowledge. However as problems become more convergent and interdisciplinary [37] it becomes harder to make determinations of right and wrong from the constrained view of one discipline, since each discipline has its own epistemological stance. In other words, does deep knowledge within an engineering discipline also confer the ability to address the moral aspects of the discipline? As long as our actions are isolated and problems simple then acting within the constraints of a discipline would not seem to create issues, but as we become more connected, this issue becomes more problematic.

Philosophers and religious figures have long sought to define frameworks for right action. From Kant's categorical imperative to Mill's framing of right action as maximizing happiness there are many possible frameworks a student can adopt. The discussion of simple, complicated, and complex framed here was presented in a different format by Aristotle, who framed ethical action as arising from both virtues and practical wisdom, or being able to judge what the right action should be. Developing practical wisdom requires life experience, however. If one frames the development of such wisdom as an iterative and continual process of action and reflection it would seem to require not just learning, but making, ethical choices while a student. A dilemma is that it is difficult for degree programs to set up scenarios where students can make such decisions without the artificiality of case studies and simulations. What "would have" happened lacks the vital force of belief William James discussed [38]. And thus until we can find something that matters to students that also lies within their domain of action, it would seem difficult to develop practical skills in ethical decision making.

We end this journey with the reflection that perhaps the key to ethics does not like with rules, case studies, or philosophy, but rather the question of what matters to me, now, in this context? Since part of being human is to be related to others one insight into ethics education may lie not in cases or codes, but in how we define our relationships to others. An engineer can create any artifact and technology and justify its impact as causing good in the world by ideology shopping, However for others to see the good in it and the meaning it has to them it must relate to them somehow. And such relationships must not just be to other engineers but to the world at large. This then is the purpose of diversity, and its practical implementation as equity and inclusion, to provide the breadth of relationships that help us to act for good in the world. Furthermore seeing ethics as relational, defined by one's relationship to others, places the engineer firmly and personally within the larger system their work affects. Unlike rules and cases, a relational view of ethics, where the engineer is strongly coupled to the system they affect through their work, provides the opportunity for more meaningful feedback through narrative construction [39]; a topic that will be addressed in future work.

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