Making Maintainers: Engineering Education and an Ethics of Care

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1. Introduction

We start with a crucial distinction: the difference between innovation and the way people talk about it. On the one hand, there are the various *acts* that we can refer to as innovation. On the other hand, there is all the *talk* about innovation, a public discourse that we refer to as "innovation-speak." These things are related, but conceptually distinct; indeed, for over ten years now we have seen prominent professionals complain about innovation-speak as a way to defend the act of innovation. For example, in 2005 the designer and writer Michael Bierut bemoaned the "cult of innovation," complained that innovation was a "euphemism," a "bandwagon," and a "fad," and reminded his readers of a warning from the legendary designer Charles Eames: "Innovate as a last resort: More horrors are done in the name of innovation than any other."[1]

Bierut's skepticism places him in a distinct minority. Innovation-speak flourished over the next decade, despite warnings from cheerleaders of business and technology that innovation had become "the most overused word in America" (*Wired*) and the term has "begun to lose meaning" (*Wall Street Journal*).[2] Academics also began to wonder what the appealing term was obscuring. In 2008 the historian Benoit Godin began a critical history of the idea and concept of innovation; by early 2014, we (the two authors of this present essay) were regularly pointing out the overuse of the term "innovation" in our classrooms, at conferences, and in online discussions.[3] We published our views in the online magazine *Aeon* in a 2016 essay titled "Hail the Maintainers,"

which laid out a critique of innovation-speak and proposed an alternative vision of technology-in-society with maintenance at the center.

The starting point of our critique is a simple idea: innovation-speak does not adequately capture the essence of human life with technology. It is true that our culture's recent obsession with innovation has generated a deeper and more meaningful understanding of where innovation and innovators come from. Innovation is important. It has played an essential role in economic growth and improved quality of life.

But this focus on innovation has an unfortunate side effect, which has been to obscure so many other aspects of technology and its social consequences. More troubling, innovation is often treated as value-in-itself and as a panacea: technological change will save us without ever having to enter into human dialogue. At its most extreme, innovation-speak actively devalues the work of most humans, including most college graduates, and could actually harm the self-conceptions students who end up in completely essential but non-innovative careers. To put it another way, chronicles of various acts of creation and innovation are not one and the same as the totality of human experience with technology. Indeed, when we reflect on human life with technology, we conclude that most human effort around technology involves maintenance, repair, upkeep, and mundane labor.

Our purpose in this essay is to offer a holistic picture of human life with technology and give suggestions for how education might be aligned with this picture. We will focus on engineering education because innovation-speak is particularly rampant in that domain. We will argue in the

end that reorienting engineering education around an ethics of care provides a new and refreshing vision that liberates us from the constraints of innovation-speak. In turn, this creates space for both innovative and non-innovative work and provides a more accurate and grounded vision of technology and society. The entirety of the subjects we are engaging—from innovation-speak, to the social roles of the maintainers, to the ethics of care—are rooted in the stories we tell each other about the world. If we are correct in arguing that we would be better off once we move past our societal obsession with innovation, our first steps should be to change the tales we tell about technology and society.

2. Innovation-Speak and the Transformation of American Universities

Use of the word "innovation" has increased greatly since World War II and even more intensely since the 1990s, but this shift builds on a much longer history of technology and culture. Recent work by historians like Deirdre McCloskey and Joel Mokyr suggests that one important source of the British Industrial Revolution was a cultural revaluation of work, technical knowledge, and material novelty.[4] As invention was accorded increasing social status, more bright and capable individuals went into the business of invention and the exploitation of nature. In the United States, these cultural developments were associated with heroes like Benjamin Franklin. More explicitly, by the 1850s and 1860s, popular authors, such as Samuel Smiles, celebrated engineers both as idols who brought material improvements to the lives of many and as paragons of Smiles' moral ideal of "self-help." By the late 19th century, a "cult of invention" had developed around popular figures, like Thomas Edison and Alexander Graham Bell.

In the early 20th century, corporations started building R&D labs to institutionalize the method of invention and build corporate strategies around continuous and predictable patterns of innovation.[5] The pioneers of industrial R&D figured out how to harness the imagery of invention for the purposes of marketing and self-promotion. Two prominent examples were General Electric's "House of Magic" and General Motors' annual model changes, auto shows, and industrial musical films.

This corporatization of invention—both as a material reality and as corporate imagery to hawk on the market—often went hand-in-hand with a deeper cultural reliance on material progress. Scholars refer to this reliance as the "technological fix," which is a fundamental faith that deep social problems can be resolved simply though technical change, rather than through a political rearrangement of social structures. In the post-WWII period, this worldview in the United States increasingly became tied to an anti-communist celebration of free enterprise, such as the Kitchen Debate in Moscow and Disney World's EPCOT Center—the Experimental Prototype Community of Tomorrow—that received support from a number of corporations.

The discourse of "innovation-speak" developed in this context, and it stemmed from multiple sources. One of the most important for our purposes is the rise of the economics of innovation, or more broadly "innovation studies." In the late 1950s and 1960s, economists, like Robert Solow and Kenneth Arrow, hypothesized that technological change, or innovation, was a significant factor in economic growth. Within a few years, this hypothesis had hardened into orthodoxy within some schools of economic thought. The notion of innovation increasingly became tied to technology, and the term "technological innovation" took off in the 1960s.[6] A turn to making

innovation a normative aspiration—something we *should* do, rather than something that just happens in the world—was significantly enhanced by the rise of "innovation policy" in the late 1970s, which asserted that government activity could and should increase innovation.[7]

The connections between innovation and fear in economic policy were supported by American foreign policy. In the two World Wars and throughout the Cold War, American policymakers agreed that military superiority depended on scientific and technological superiority. This consensus drove substantial investments in conventional weapons, more lethal chemical and nuclear weapons, new approaches to naval, aerial, and space vessels, and basic science investments in solid-state components and computing devices.

Even after the end of the Cold War and the emergence of the United States as the world's sole military superpower, fear continued to be a powerful motivator for American innovation policy at home. In the United States, the turn to innovation policy was directly tied to a cultural fear of Japan, particularly economic competition from that nation but also a worry that the Japanese would take over US institutions and push their cultural practices on American workers. From that time forward, innovation-speak has been a discourse of fear. Rust Belt towns that were falling behind sought to make themselves the next Silicon Valley. Businesses paid oodles to professor and consultant Clayton Christensen, who coined the term "disruptive innovation," in the hopes that he could help them avert the possibility of their companies being overthrown by outsider, upstart firms. Corporate executives, university presidents, and science policy gurus increasingly told stories about how the American education system was falling behind, especially

when it came to science and technology, and about how young people would be cast adrift unless they received degrees in so-called "STEM" fields.

Moreover, since the 1980s, American universities have increasingly been remade in the corporate image, and most of the changes have been made in the name of innovation. As Philip Mirowski and others have detailed, new laws and other institutional changes have been aimed at turning universities into patent factories.[8] The Bayh-Dole Act of 1980, for instance, allowed researchers to patent inventions created through federal funding, something that had previously been verboten when the running assumption was that federal money should benefit public rather than private goods. As corporations have scaled back expenditures on R&D, the National Science Foundation and other funders have increasingly become focused on knowledge that is exploitable in the short term, rather than on long-run basic science. In their grant proposals, scientists and engineers have to claim that they are doing something novel and innovative rather than advancing fundamental scientific knowledge. University business models have become more and more dependent on the "overhead" from sponsored research, and university administrators have come to measure the value of faculty members by how much grant money they can pull down.

Universities have also come to accept the idea that it is their core mission to create *innovators*. Often this impetus goes hand-in-hand with a celebration of STEM education, with scientific and engineering knowledge being seen as the key to innovative activity, but current focus on innovation and entrepreneurship in higher education goes well beyond the bounds of STEM.[9] The University Innovation Fellows (UIF) program, which also has an essay in this volume, is a

good example of this wider cultural trend. Initially funded by the National Science Foundation, the UIF is a training program and social network for students at all levels of university education. UIF encourages students to imagine themselves as "change agents" who must disrupt the stodgy ways of their universities and introduce innovations. Armed with sticky notes, white boards, and a "fail fast" mentality, the students are "empowered" to value discontinuity, novelty, and change rather than continuity, tradition, and care. They go down this path of disruption with little reflection on what ends such changes are meant to accomplish. Innovation is assumed to be a value in-itself: the UIF's website is filled with words like change, innovation, creativity, and entrepreneurship with minimal reflection on what changes are desirable or what ends are hoped to be reached. While it is unclear what values motivate the UIF—beyond the non-value of change for its own sake—it seems certain the fellows get a deep education in creating hype.

Taking all of these recent historical developments together, it's clear that the "innovation" idea is more than an overused business slogan. It has come to form the basis of a thoroughgoing reform of basic cultural institutions including but not limited to schools and universities. "Innovation" has become the yardstick in universities both for the outcomes of faculty research—patents and grant money—and for outcomes of undergraduate education—STEM majors winning high-paying jobs in tech sectors.

Innovation-Speak and the Training of Engineers

Engineering schools have become particularly fertile grounds for innovation-speak. Many engineering students now take required courses in entrepreneurship and design sequences focused on innovation. These students are rarely told that the narrative of innovation-speak,

particularly versions having to do with STEM education, also serve the economic interests of these schools. The rhetoric of "innovation" and high-paying engineering jobs becomes a natural and almost effortless form of marketing in today's culture of uncertainty and anxiety, including the very real concerns about the cost of education, student debt, and return on investment.

The innovation focus in university engineering schools builds on long traditions within engineering education and the engineering profession, which typically center on invention and design. Engineering degrees typically end with capstone or "senior design" projects that involve the creation of new things, not with more mundane (and realistic) engineering undertakings. For example, engineering students often help build robots or electric cars, build a computer program, or create remotely-piloted drones. Yet, most engineers do not take part in design activities once on the job. Professional engineering societies reinforce this focus on design and novelty in several key ways. They hand out awards and fellowships primarily to engineers who have created new technologies rather than to engineering leaders who have played fundamental roles in keeping systems and enterprises running smoothly. The IEEE's highest award, the Medal of Honor, for instance, has as its evaluation criteria "substantial significance of achievement, originality, impact on society, impact on profession, publications, and patents related to achievement." Lists of recent winners make clear that these criteria are understood in terms of invention and innovation. Similarly, the National Academy of Engineering's Draper Prize—its highest prize—typically rewards new inventions.[10] Moreover, in 2008, the National Academy of Engineering put out its Grand Challenges for Engineering, which are almost wholly described in terms of creating new things to solve deep social problems—the technological fix writ large.

But some proposals to reform engineering education go further, arguing that it should be remade in the image (and language) of Silicon Valley. One clear example of this today is the so-called Big Beacon Movement in engineering education, which, borrowing from the "revolutionary" language of innovation-speak, invites "interested individuals, students, parents, educators, employers and other change agents to come together to disrupt the status quo." Unsurprisingly, Big Beacon receives a laudatory shout out on the homepage of the University Innovation Fellows, which itself views universities as backwards, bureaucratic organizations in need of revolutionary change. In their book, *A Whole New Engineer: The Coming Revolution in Engineering Education*, Big Beacon co-founders, David Goldberg and Mark Somerville, put forward a vision that badly misrepresents the nature of technology and society.[11] The entire book is conceived in destructive and fearful terms: "Invitation to Collaborative Disruption: Will Disruption Shape Us, or Will We Shape It?" On top of chapters full of buzzwords ("Changing How We Change: From Bureaucracy to Change Management"), four of the book's nine chapters contain the phrase "whole new." According to the authors, we need "whole new" engineers, learners, professors, even a "whole new" culture. But is there really nothing in our culture worth preserving? Is it really true that the technologies around us are entirely new, or should be? Is it even imaginable that engineers will deal only with the "whole new" rather than having to learn how to wisely manage and maintain the quite old?

3. Engineering is Maintenance

If you adopt even a modestly critical point of view, you will quickly conclude that the rhetoric in works like *The Whole New Engineer* is simply out of touch with ordinary life. If you look at the room around you, you will see many mundane technologies—including tables, chairs, light

bulbs, bookshelves, books, electric fans—that have gone through long processes of incremental change but have been largely unaltered for decades, even centuries. Just behind the walls are other technologies—water and waste pipes, HVAC ducts, electric wiring—that are similarly old and unremarkable. If you commuted today, you likely crossed roads, bridges, railroad beds, or subway systems that would not have looked surprising or foreign to someone living in the 1920s. Many of the technologies that you have used to live today, electric or gas stoves for cooking your breakfast, running water for washing your dirty body, toilets for sending your waste away, are not whole new, are not revolutionary, are not innovative in any significant way, and yet are totally necessary. Moreover, the vast quantity of human labor both is aimed at keeping these fundamental systems running, rather than at introducing wholly new technologies, and relies on these systems to keep human society going, for instance, by prepping food to keep us from starving. According to one study, over 70% of engineers work on maintaining or overseeing existing systems rather than designing new ones.[12] Furthermore, there are many technological systems, like electricity, water, phone, and Internet services, that we do not want to see "disrupted'; rather, we value reliable, continuous, high-quality service.

Unfortunately, it is not only engineering education that misses the fundamental importance and ubiquitous nature of maintenance. Much of the scholarly literature about technology fails to reckon with these basic facts of ordinary life with technology. Because historians and others who study the social dimensions of technology grew up in a culture that celebrated and centered on invention and innovation, their work too has been centered on these phenomena. While a few classic works emphasize the centrality of maintenance and repair for sustaining and conserving society, in most technology studies, maintenance, repair, and upkeep are largely ignored,

rendered invisible.[13] The scholarly focus on invention and innovation has greater consequences than simply creating "gaps in the literature." After all, how are engineering professors and other educators to learn and teach about the broad history of their fields technologies if the available literature focuses so narrowly on invention?

Mercifully, a growing body of literature has started to improve this situation. Ruth Schwartz Cowan, for instance, in her classic study *More Work for Mother* examined how women's housework, much of it maintenance-focused, perpetuated and sustained family life.[14] Another touchstone book in maintenance studies, David Edgerton's *The Shock of the Old* emphasizes that most basic technologies around us are old rather than new, ordinary rather than novel. Edgerton points out that one reason it is difficult to talk about maintenance as a social process is that it often is not counted in economic metrics. Canada did ask about maintenance costs for many years in an economic survey. For those years, maintenance accounted for between 11 and 21 percent of GDP, a vastly higher number than innovation-centric expenditures, such as spending on research and development (R&D), which only comprises about 2% of GDP in OECD countries today.[15] Moreover, the study of maintenance and repair has greatly expanded in the last decade.[16]

The real shame of the matter is this: a more holistic, sober, and accurate picture of human life with technology has been around for decades, and some of the authors who have put it forward, like Ruth Cowan, are relatively well-known beyond the boundaries of the small field of technology studies. The evangelists of innovation and who buy too wholly into the rhetoric of the "whole new" are acting irresponsibly by ignoring diligent research that has actionable insights.

Once a more grounded vision is established, it is easy to see that most engineering work will always be dedicated to maintaining and conserving existing technological systems and using those systems for production, not in introducing new systems. Because of the way that industrial societies have developed, it could not be any other way. Most civil engineers work on keeping up existing physical infrastructures, like roads and bridges. Even in "cutting-edge" fields, like software, about 70% of budgets go into maintenance and upkeep, whereas only about 8% of budgets go into new design, as historian Nathan Ensmenger has noted.[17] Moreover, the structure of the engineering workforce means that most engineers work with large-scale technological systems, where companies create value through quality of service. These engineers know that radical or revolutionary changes usually do little more than irritate customers—and these customers tend to complain to regulators and their elected representatives.

To summarize, most engineers are going to be Maintainers, and if we include our perspective to include all workers, not just engineers, the percentage of Maintainers will be even higher. Yet, innovation-speak actively devalues this essential work, which will never be radical, revolutionary, or "whole new." As a discourse that is shoved down the throats of young people, innovation-speak has the potential to generate false and harmful self-images as innovators when they end up in jobs that are essential but basically non-innovative. This can lead to real disillusionment, not only with society at large but with specific authority figures, with students feeling they've been lied to by their university, their professors, and maybe even their parents who encouraged them to pursue engineering. We have heard several anecdotes from leaders in business and education that acknowledge the crux of the problem: prevailing rhetoric encourages

everyone to be entrepreneurial innovators who come up with big ideas; but all organizations need many more people who can maintain and execute—in other words, who can simply get things done. Given the moral hazards of innovation-speak, is there a better way of thinking and telling stories about the role of technology in society that can offer a holistic vision of maintenance *and* innovation? We believe so, and we think it is rooted in an ethics of care.

4. An Ethics of Care

In the opening sections we described a trend: American culture is saturated with the ideology of innovation-speak, and that ideology's celebrated concepts of entrepreneurship and disruption have seeped into engineering education. This trend is troubling because it misrepresents the character of the work that actual engineers do. We believe these students—and the communities they serve—will be better off if they replace notions of innovation and disruption with an ethics of care. The ethics of care arose as part of feminist theory in the late-20th century, most famously in Carol Gilligan's 1982 book, *In a Different Voice*.[18] The starting point for the ethics of care was a fundamental critique of existing ethical paradigms. Gilligan and others believed these paradigms were overly abstract and intellectual and, therefore, did not reflect how ethical decisions were actually made in ordinary, everyday life.

The ethics of care is rooted in a few basic ideas. First, we are fundamentally dependent on one another—a conceptual departure from classical liberal theory, which cast us as basically independent and autonomous. Here, our background in technology studies compels us to add that one way we depend on each other is through technologies and infrastructures, which require massive collaborative and coordinated efforts to sustain. Second, our decision-making must first

attend to the marginal and vulnerable. Such a perspective is often left out of innovation-speak, which brackets how technological change affects people. Silicon Valley, the kingdom of the innovation-mouthed, is a horribly unequal place, where multiple poor families pack into small ranch houses just to make ends meet.[19] Third, rather than being rooted in abstract principles, our moral choices should attend and respond to the immediate conditions of our context. Indeed, the ethics of care can be thought of as an ethics of responsiveness.

We find the ethics of care to be a helpful way of thinking about all education, including engineering education, particularly because the ethics of care reorients us to thinking about ends rather than means. For instance, for many people, the goals of a just society are to provide a high quality of life to all in an environmentally sustainable manner. Obviously, there are many different ideas about how best to reach these goals, and often discussions about these issues founder on some traditional divisions. Some individuals believe that the "free market" provides the optimal society and that government intervention can only interfere and degrade these processes, while others assert that the state has an active role to play improving life for all.

Ultimately, then, the ethics of care pushes us to have explicit conversations about values—or put another way, what we each value. Clearly, there is no unanimity or even rough consensus around the values our society holds dearest, since we live in a diverse social world with many different individuals and groups who hold many different, sometimes conflicting, values. To make matters more complicated, the United States has increasingly become a partisan society: members of different political parties do not like each other. Yet, when we help students to reflect on their actual cares and values, what they say often flies in the face of the ideology of

innovation and entrepreneurship. For instance, a colleague noted that one of his engineering students—a young man who immigrated with his family from India—found innovation-speak wholly alienating. The student was interested in finding a good job that would allow him to provide for his parents, siblings, and his eventual wife and children. In other words, his actual values were oriented towards interconnection and care. Our point is that his ultimate work as an engineer would likely be similarly oriented. If he came to work as a power systems engineer for an electric utility, the reliable electricity he would work to produce would help run medical devices and other technologies that keep people alive. This work is critical, even if it has nothing to do with innovation.

We know that engineers are more than capable of reflecting on the fundamental values that their work engages. Engineers often conduct such reflections through the vehicle of their professional societies' codes of ethics. Let us focus briefly on the Code of Ethics of the American Society of Mechanical Engineers (ASME): as with many other engineering societies, ASME's code focuses primarily on the need for engineers to be objective, fair, and honest in their business dealings.[20] In other words, the code largely relates to ensuring and increasing the social status and prestige of engineers and toward supporting the healthy functioning of capitalism by avoiding crime and corruption. But some aspects of the code go beyond such professional matters. ASME's code is built on three fundamental principles. The first holds that engineers should use "their knowledge and skill for the enhancement of human welfare." This notion is further elaborated in two of the eight "fundamental canons," which build on the fundamental principles. Canon one asserts that "engineers shall hold paramount the safety, health, and welfare of the public in the performance of their professional duties." And canon eight reads, "Engineers shall consider environmental

impact in the performance of their professional duties." While these principles and canons are fairly vague and certainly leave a great deal of leeway for interpretation, they can be used to start deeper conversations about values. At a bare minimum, they should remind us that engineering goes well beyond innovation.

Put another way, much of modern life depends on well-functioning technological systems, and the vast majority of human work will always be aimed at maintaining them—that is, the labor is oriented towards taking care of the world and its inhabitants. This work is essential, and we should value it. Yet, care also involves change. If we find a way to better care for the world, we should do it. But not in ways that degenerate the quality of life for others.

For engineering education, this means that we must strike a balance between pedagogies that value maintenance and innovation. Innovation is important, and it should be a part of engineering programs. We know that some reliable factors hamper innovation processes and lead to so-called innovation "valleys of death," and we should teach our students how to surmount these barriers if they can. We also need to ignite the imaginations of young people, to nurture their creativity, and to teach them that they should resist the arbitrary exercise of authority. But such lessons need to sit in a more expansive context and broader moral compass: engineering is fundamentally about caring for technological systems, the humans that rely on them, and the natural environments that surround them. Innovation is but a small part of that overall process of stewardship.

For sure, we see precursors to the ethics of care in long-running engineering traditions. For instance, during the 1920s and 1930s, the high moment of engineering progressivism, Hebert

Hoover and other influential figures worshipped at the altar of "efficiency."[21] Increasing efficiency often involved the introduction of new technologies and processes—innovation in today's language—but it was carried out in the name of *conserving* resources, both financial and natural, and reducing *waste*, an important moral term of that period. In other words, efficiency was more focused on ends than means.

Although it has been around since the 1980s, the ethics of care framework and examples focused on operations and maintenance have made little headway in engineering education and the ethics courses and modules that make up engineering curricula. To give one example, Gail Baura's textbook, *Engineering Ethics: An Industrial Perspective* (2006), in many ways a strong work, contains thirteen case studies of ethical problems.[22] Yet, of these, nine are wholly or mostly focused on the early stages of technology—design, research, and development. As we have seen, roughly 70% of engineers actually spend their work time focusing on maintenance and the oversight of existing technologies. In this way, most existing engineering ethics texts do not reflect the actual work that engineers will do, in part because they buy into the ideological self-image of engineers as *creators*.

Moreover, as mentioned above, these texts do not fit engineering students own moral self-understandings. In an interesting study, the engineer Angela Bielefeldt introduced 64 engineering students to five standard frameworks for thinking about ethics (rights ethics, duty ethics, utilitarianism, virtue ethics, and ethics of care) and asked them which theory was closest to their own moral worldview.[23] The largest number, 18, chose the ethics of care, a view usually not even covered in such courses. Furthermore, this choice had a strong gender and racial/ethnic

component. About 40 percent of women in the course chose the ethics of care (as opposed to 23% of their male counterparts), and a staggering 57% of Hispanic American students made the same choice. These findings suggest that standard engineering education may actually alienate women and minorities by limiting them to moral frameworks that do not accord with their actual beliefs and experiences. As Bielefeldt suggests, "Teaching engineering ethics through the ethics of care may be helpful to retain women and minority students," a constant, well-known problem in the engineering field.

When it comes to teaching the ethics of care, engineering has much to learn from other fields and disciplines. K-12 education and the healthcare fields have made the approach a central feature of their training programs for decades.[24] Put another way, engineering educators do not need to invent anything from scratch, but can effectively adapt thinking and teaching tools from other fields. For instance, the political scientist Joan Tronto divides caring into four phases:

1. caring about, in which the caregiver realizes that there is a potential problem;
2. taking care of, in which the caregiver decides the proper course of actions;
3. caregiving, in which the action is carried out, and
4. care receiving, in which the caregiver assesses the success of the action.[25]

This simple ethics of care schema alone—and there are several others of its type—has broad applicability in engineering practice and is something not covered in most engineering education. Moreover, it touches on real and serious moral lapses in the history of engineering—from the spectacular, like Enron using fake maintenance to spike energy prices and induce blackouts, to the mundane, such as the fact that maintenance workers are often the most frequently injured and killed in industrial operations—that could act as cases for this approach.

Moreover, taking the ethics of care seriously means that, in addition to courses on innovation and entrepreneurship, engineering programs need to introduce more courses, experiential opportunities, and capstone projects that focus on conservation, maintenance, and upkeep. There are multiple ways to introduce engineering students to themes of maintenance. First, students should be introduced to how corporations and engineering professionals manage maintenance regimes. Melinda Hodkiewicz, an engineering professor at the University of Western Australia and a member of the Maintainers network, regularly teaches basic maintenance theories and concepts in her classes. She believes that, at a minimum, students should be introduced reliability-centered maintenance (RCM), a formal and standardized process for managing system maintenance. But her own teaching goes far beyond these basics, and she has some evidence of success. One of her students started internship with a petroleum company and wrote to her soon afterward to thank her: "Everybody in the team was really impressed that I had previous exposure" to basic maintenance theories and concepts.[26] "Pretty much everything I learned in [Hodkiewicz's class] is what I'm using in practice. It saved them a lot of time when they were explaining the scopes I'd be responsible for and also made me look great the first week I started." In other words, introducing students to maintenance is important because often it is what they will be doing on the job.

Second, even as students learn about innovation, they should do so with an emphasis on its inherent relationship to maintenance. For example, students should also be introduced to the notion of designing for easy and efficient maintainability. Here ethical and political topics are unavoidable. Since corporations introduced practices of planned obsolescence in the 1920s, they

have designed for the opposite of maintainability, particularly when it comes to consumer products. Some firms go even further, creating what some call "forced obsolescence." For example, Apple stops supporting and updating its iPhones after a putting out a certain number of new products and system upgrades. Even when older phones are still fundamentally sound, they become basically un-useable. Given that cellphones involve many environmentally-unfriendly and politically-problematic parts and materials, forced obsolescence raises serious moral questions. Designing for maintainability involves certain established practices, but it is also a rich opportunity to involve students in ethical discussions about what they owe other humans in their professional lives.

Third, maintenance and upkeep can and should form the basis of capstone projects. Such projects could take many forms. Of course, this could be as simple as introducing students to how the university's facilities and physical plant staff keep the school going. Other options include having students maintain university depositories of student and faculty publications, having computer science students work with updating and altering backend legacy code, and working with local transport and infrastructure organizations, whether private or public, to manage and update systems maintenance routines, particularly if the organization's practices are inadequate or out-of-date. We think that environmental engineering and sustainability management provides a particularly rich way to explore these issues, however, and that they should be required of more engineering students. Achieving a more sustainable future that greatly reduces the amount of greenhouse gases being emitted will of course require innovation. But it will also involve rethinking how we use our resources, maintain our physical infrastructures, and take care of the world around us.

In the end, ethics of care probably requires engineering students to be educated in the politics of technology and society—something that the relatively "apolitical" engineering tradition might find hard to swallow. This isn't about indoctrinating students into any particular political view. We find aspects of the Maintainers both in certain forms of conservatism, which argue that we have a moral duty to care for what we have inherited from our ancestors, and in certain forms of progressivism, which assert that healthy capitalism requires active intervention, particularly around issues like pollution, safety, and the well-being of public works. Care requires holistic, or systems, thinking that goes far beyond the individualist fantasies of innovation-speak with its pantheon of Great White Men: Gates, Jobs, Bezos, Zuckerberg, Thiel, Musk. It requires us to realize that we are dependent on each other and on the technological systems and infrastructures that many, including those who have come before us, have erected, systems and infrastructures that now require our attention and safekeeping, even when such work bores our pants off and pales in the light of nifty, new, glittering gadgets.

5. Conclusion: Making Maintainers

In this essay, we have argued that, since the 1960s, American society has increasingly become dominated by innovation-speak, an ideology that glorifies technological change as the answer to society's problems. Countering innovation-speak is important not because it is an annoying way of talking, though that is true enough, but because of two important reasons: first, innovation-centrism offers at best a partial view of human life with technology. Second, reforms made in innovation's name—including changes made to all levels of education—are at best questionably effective and at worst deeply damaging to the traditional roles and practices of institutions. We

have also argued that there are better ways of thinking about ordinary life with technology, which start by focusing on the bulk of human practices with things, including maintenance, repair, and mundane labor. The differences between these two views have important implications for education, and we have tried to articulate how maintenance-centered thinking can be used to reform and improve engineering education. We have tried to show how the ethics of care can provide a holistic vision of engineering education that includes both upkeep and innovation, but does not overly privilege the latter.

We have also discussed how engineering education requires more focus on values and ends, and we find innovation-speak particularly lacking on this front: innovation is not a value in-itself, though it is often treated like one in contemporary society. Yet, there is one area where innovation-speak currently outpaces the more grounded vision of technology put forward in this essay, and that is when it comes to putting forward positive visions of the future. Certainly, one thing about the current imagery and ideas around innovation that captures young minds is the techno-utopian fantasy of a better future, to which individual innovators can and will contribute. Consider, for instance, the excitement generated by Elon Musk's announced plans to go to Mars.

As yet, the focus on maintenance and Maintainers has nothing comparable. In part, this stems from an image problem: Maintenance and infrastructure aren't sexy. The comedian John Oliver pointed this out in a segment on infrastructure on his show, *Last Week Tonight*. In the end, he argued, "No one has made a blockbuster movie about the importance of routine maintenance and repair," and went on to imagine a star-studded non-action film titled *Infrastructure*. In the real world, we see this difference between innovation and maintenance play out when elected

officials have incentives to take part in photo ops and stand in front of ribbon cuttings for new infrastructure but little incentive or opportunity to take credit for existing things working well. Moreover, we are living in a moment of perceived cynicism and pessimism: as the philosopher Slavoj Zizek suggests, we have few utopian, or at least non-dystopian, visions of tomorrow in popular culture, which often seems to primarily consist of zombie stories and tales of environmental apocalypse. For a variety of reasons, then, we lack a picture of a positive future that includes well-ordered and maintained technological society that does not involve radical technological change.

Yet, we believe it is incumbent on all of us to put forward such a positive vision. Students in all fields, including engineering students, should be involved in such visionary practices from the start of their educations. But current techno-utopian visions are far too focused on innovation and radical technological change and basically ignore politics and conservation of the ordinary and mundane. Here are some examples that can be used to kick start grounded discussions of positive tomorrow: the American Society of Civil Engineers regularly gives American infrastructure low grades in its infrastructure report card. What would it look like if the country got straight A's? How would we get there? These same questions can be asked of overhauling American drinking water systems. After experts established that the water system in Flint, Michigan, was poisoned with lead, the same was found of hundreds of other water systems around the nation. As a massive political and engineering project, how can we transform our current systems and ensure clean drinking water for all? Finally, many, perhaps most, existing homes and buildings throughout the United States are extremely energy inefficient, and yet decreasing energy use is one of the most important ways to manage global climate change. How could we create a

program to rehabilitate all existing buildings and bring them in line with energy standards, such as LEED? How would such a program work?

In asking these big questions, and putting them in the form of a challenge to students, we are expressing our confidence that we can together come up with compelling answers. In many cases, we suspect that there is a place for innovation and novelty in some of the projects we describe above. Wouldn't it be nice to see innovation put to work in the service of maintaining and caring for our ailing technological society? Indeed, we argue, the nation faces a vital moral imperative to make maintainers.

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