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Activist Engineering: Changing Engineering Practice By Deploying Praxis

Darshan M. A. Karwat · Walter E. Eagle · Margaret S. Wooldridge · Thomas E. Princen

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Abstract In this paper, we reflect on current notions of engineering practice by examining some of the motives for engineered solutions to the problem of climate change. We draw on fields such as science and technology studies, the philosophy of technology, and environmental ethics to highlight how dominant notions of apoliticism and ahistoricity are ingrained in contemporary engineering practice. We argue that a solely technological response to climate change does not question the social, political, and cultural tenet of infinite material growth, one of the root causes of climate change. In response to the contemporary engineering practice, we define an activist engineer as someone who not only can provide specific engineered solutions, but who also steps back from their work and tackles the question, *What is the real problem and does this problem "require" an engineering intervention?* Solving complex problems like climate change requires radical cultural change, and a significant obstacle is educating engineers about how to conceive of and create "authentic alternatives," that is, solutions that differ from the paradigm of "technologically improving" our way out of problems. As a means to realize radically

D. M. A. Karwat (✉) · W. E. Eagle · M. S. Wooldridge
Department of Mechanical Engineering, 2293 GG Brown, 2350 Hayward, Ann Arbor, MI 48109-2125, USA
e-mail: dippind@umich.edu

W. E. Eagle
e-mail: eeagle@umich.edu

M. S. Wooldridge
Department of Mechanical Engineering, 2156 GG Brown, 2350 Hayward, Ann Arbor, MI 48109-2125, USA
e-mail: mswool@umich.edu

T. E. Princen
School of Natural Resources and the Environment, 2506 Dana Building, 440 Church Street, Ann Arbor, MI 48109-1115, USA
e-mail: tprincen@umich.edu

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new solutions, we investigate how engineers might (re)deploy the concept of *praxis*, which raises awareness in engineers of the inherent politics of technological design. Praxis empowers engineers with a more comprehensive understanding of problems, and thus transforms technologies, when appropriate, into more socially just and ecologically sensitive interventions. Most importantly, praxis also raises a radical alternative rarely considered—*not* "engineering a solution." Activist engineering offers a contrasting method to contemporary engineering practice and leads toward social justice and ecological protection through problem solving by asking not, How will we technologize our way out of the problems we face? but instead, What really needs to be done?

Keywords Activism · Activist engineer · Climate change · Praxis · Ethics · Paradigm · Social justice · Ecological soundness · Sustainability · Responsibility

Introduction

Contemporary engineers frame climate change as a "carbon problem" requiring a technological solution (Karwat 2012). In this paper, we investigate this attitude toward climate change by highlighting the absence of historical and political discourse in engineering education, with a desire to explore how we as educators, practitioners and activists might change this engineering "paradigm" (Kuhn 1962 [1996]). We focus on how engineers frame and solve problems, and in particular on the challenges involved in proposing authentically alternative and radical solutions to climate change. We do this by presenting a brief analysis of interviews of contemporary engineers working on technological responses to climate change, and then by interpreting aspects of the current engineering education and practice paradigm that have led to the tendency to technologize our way out of the problems we face. This discussion leads us to propose a new broad engineering education and practice framework, grounded in the concept of *praxis*, to produce activist engineers.

We propose that activist engineers be trained holistically and be equipped with tools and ethics to evaluate problems socially and ecologically, thereby moving engineering beyond being a profession solely focused on technological development. Activist engineering requires engineers to seek out non-technical knowledge from communities and places where socioecological problems exist and requires that engineers be trained to understand and use such knowledge competently. Praxis redefines engineering responsibility, education, and problem definition. To make things more concrete, we explore how an activist engineer might address climate change: for example, activist engineers can promote localized alternative energy solutions that incorporate community values; they can try to obviate the need for the risks of geoengineering; or they can change the metrics to evaluate the efficacy of engineering work from profit and material growth to community resiliency and self-sufficiency. By challenging the current engineering paradigm through praxis, the activist engineer can radically transform the engineering profession to align engineering interests with social justice and ecological stewardship.

Contemporary Engineers on Ecological Problems and Climate Change

Climate change, which is likely to show significant and increasing effects over the coming century and beyond (Beck 1992; Princen 2012; Nixon 2011), represents a fundamentally new kind of problem to societies, and to engineers in particular. Dealing with climate change demands a new spirit of socio-technical interaction (Jonas 1984). How might it be addressed—or “solved”—according to contemporary engineers? The following quotes are responses to this question taken from interviews that one of the authors of this paper conducted with practicing engineers at the third Sustainable Alternative Fuels in Aviation Workshop organized by the International Civil Aviation Organisation (Karwat 2012):

> I have always believed people are smart enough to do what they want. As soon as we figure out that we have a problem, we usually can muster up the resources to solve it. [Technologically] is the only way you are going to solve [climate change], I think.
> *CEO of a genetic engineering company that makes biofuels*

> Technology can’t solve climate change because we don’t have the political will to get started. If we do, when we do, the technology will be there…We are not bringing technology to bear on the problem today…Other than an unwillingness to apply technology, it is not clear to me that there are [ecological problems that technology cannot solve].
> *Aviation and environmental consultant, and winner of the 2007 Nobel Peace Prize as part of the Intergovernmental Panel on Climate Change*

These quotes show how many engineers view and frame problems of climate change and sustainability as technological deficiencies, in line with the thinking of René Descartes and Francis Bacon, two Enlightenment philosophers, who believed we must constantly move away from an imperfect past through technological development (Davison 2001).[1] According to the current engineering paradigm, the imperfect past and the current reality is that carbon dioxide emissions are causing climate change. Solutions to climate change thus take the shape of technologies that absorb carbon dioxide or do not emit carbon dioxide—for example, biofuels made from corn; mountaintop removal for coal coupled with carbon capture and

[1] Davison (2001, p. 69) writes, “In the world Descartes and Bacon saw, external limitations are overcome, and thereby progress attained, to the extent that rational knowledge about natural machinery takes over from the inefficient meandering of evolution. A lack of rational development in existing social practices, a lack of material advance, i.e. a lack of progress, appeared as backwardness, idleness, moral decay. Yet, notions of progress and stability do not stand over and against each other so much as they inform and shape each other. The Enlightenment idea of stability was derived instrumentally from the antecedent metaphysical conviction that the purpose of social life was to develop the raw stuff of existence into a rational form, a Paradise on Earth.”

sequestration; seeding the oceans with iron to create algal blooms that will absorb carbon dioxide, and so on.

It thus seems, significantly, that engineered responses do not address the problem of climate change as originating from the expansion and use of technologies, but rather as a detrimental byproduct of the use of particular technologies—a deficiency that can be corrected through newer technologies. We argue, however, that the adoption of more advanced technologies, unless accompanied by requisite social changes, is just another turn of the old technological crank. These technologies, like the ones before, have ecological costs and continue to create an illusion of infinite material growth and consumption into the future while providing a placebo of action in response to climate change. We now briefly examine how this problem solving ethic has evolved.

The Current Engineering Paradigm

Engineers constantly make political and value claims by virtue of the work they do (see, for example, Noble 1977; Hecht 1998 [2009]). As technology developers, engineers are essential in supporting the paradigm of infinite growth through increasing resource utilization (for example, by improving efficiency and reducing process waste). In the previous section we argued that engineers see their role as helping society by constantly providing technology to solve problems. However, it is also true that our current political, economic and social structures *depend* on continued technological development. Consequently, engineering is not politically or value neutral as engineers and non-engineers may believe. Thus, engineers must be active and responsible participants in framing the issues they work on, not only from a technological perspective, but also from a political and value-based perspective.

Engineers play a pivotal role in affecting the outcomes and impacts of technologies, and they continue to be educated in ways that perpetuate the interests of materialism, of consumerism, of abundance-from-scarcity, of distributed costs and highly individualized benefits, and of violence (Riley 2008).[2] Engineering outcomes can also morph socioecologically unjust or degrading outcomes into results that have the air of positivity: as we continue to produce greenhouse gases, the economy, as popularly measured through gross domestic product, continues to grow positively. Contemporary engineers typically operate in top-down organizational hierarchies

[2] For example, in 1987, the World Commission on Environment and Development noted that more than half a million of the world's scientists worked on weapons research that accounted for 50 % of all research and development expenditures (World Commission on Environment and Development 1987). Also, as boasted by an executive vice president of Lockheed Martin in 2005, "We are the largest single supplier to the U.S. Department of Defense and the largest provider of information technology services to the federal government. We also happen to be one of the nation's largest employers of engineers and scientists, with about 50,000 of our 130,000 employees around the world holding some sort of technical degree or credential. To sustain this critical mass of talent, we will hire approximately 9,000 engineers this year, including 3,700 new graduates. In fact, in any given year, Lockheed Martin hires about one of every 20 engineering baccalaureates in the United States—four to five percent of the entire nation's undergraduate output" (Riley 2008).

(Karwat 2012) and obey authority (Riley 2008), and many claim the problems they work on are framed and handed to them by their superiors with vested interests (Karwat 2012). These claims make it seem that engineers lack agency,[3] that they are subservient to the demands of their bosses and a technological culture.

At fault is how engineers are trained to think *ahistorically* and to act *apolitically*. Engineering education does not focus on the history of engineering and technological development, or on the larger context of the socioecological impacts of technology. Instead, technological development is viewed by engineers as *a*historical; engineers tend to dissociate the shape and form of technologies from political and social pressures. To readers of engineering textbooks, technological development is made to seem cumulative and progressive, as if the shape and form of technologies is deterministic, always linearly forward-looking with each iteration better than the last, and always capable of producing more from scarcer resources. For example, new designs of solar panels or computer chips or car engines, while of course resting on knowledge gained through previous technical exercises, are to the engineer "the best we can do given what we know, *technologically.*" But omitted by engineers and perhaps considered irrelevant are the non-technical reasons why solar panels, computer chips and car engines were initially conceived; little thought is given to whether these solutions might be the best we can do given what we know technologically *and* socially and ecologically. Furthermore, many common eras in human history have been metonymized through technological development (like "The Stone/Bronze/Iron Age"), thus effectively marking the passage of history by our technological development and inferring that such transformation is inevitable.

Apoliticism is what engineer and writer Samuel Florman would call an "existential pleasure of engineering" (Florman 1976). Engineers actively distance themselves from the non-technical aspects of engineering work. Reductionism,[4] empiricism, positivism (Vesilind and Gunn 1998),[5] and dualism,[6] form the cornerstones of modern engineering and technological development, and engineers tend to ignore or dismiss considerations of intangibles like politics, emotions, and other ethical concerns (Vesilind and Gunn 1998). For engineers, engineering is fundamentally about the design of technology through material construction and manipulation of artifacts (Mitcham 1994), and the technical is considered "fact" while the political is considered "value" (MacKenzie 1990). Therefore, the socioecological and political implications of engineering work are left to be

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[3] We take "agency" to mean the capacity to make decisions and choices for oneself given one's knowledge.

[4] We understand reductionism as the division and discretization of complexity into well-defined parameters that can therefore be adjusted. An example of reductionism is how federal engineers converted the storage reservoir problem of dams into a differential equation with terms that could be manipulated. Reductionism thus sets up cause-and-effect relationships. It is also referred to as "atomism" (Hauser-Kastenberg et al. 2003).

[5] Positivism, which is the application of the empiricist tradition of Francis Bacon and Isaac Newton, allows the engineer to stand as a supposedly neutral observer to the forces of nature that dictate empirical outcomes.

[6] Dualism is related to positivism—it is the separation of humans from the environment, the distinction, particularly in Western philosophical traditions, of mind and matter.

evaluated by the users—politicians, lawyers, and business people, among others—and any ill-effects of the technology can be attributed to user error.

Ahistoricity and apoliticism leave little space in the current engineering paradigm to incorporate meaningful considerations of socioecological outcomes. A truly sustainable existence has at its core a social and engineering paradigm that creates a culture of peace, satisfaction, and sufficiency; a paradigm that is ecologically sensitive and holistic. It is the role of the activist engineer to create a new paradigm of engineering in which the engineer is equipped with not only technical tools and knowhow, but also with the requisite socioecological perspectives, knowhow and ethics that allow for activist engineering. If engineers have been essential in building and maintaining the current sociotechnical order, they must be the ones engaged and empowered to forge a new order.

Paradigmatic Change: A New Kind of Engineer

Activist engineering is engineering that seeks to fundamentally redefine contemporary engineering practice by exposing the political and value-based nature of engineering; by applying socioecological learning to technological design; by imbuing a different sense of responsibility in engineers; and by moving the scope of engineering beyond solely technological development. The activist engineer, however, faces significant barriers to change, such as engineering's historical associations with violence toward Earth and its people, militarism and empire building (Baillie 2006; Tucker 2010; Misa 2011).[7] Many technologies and large-scale infrastructures that were promoted under the guise of providing "freedom" have also resulted in significant (some might argue crippling) reliance on those technologies. The automobile is the quintessential example of such a technology deeply entwined with modern society, having played a large role not only in offering increased mobility and emergency medical services to many people, but also in the development of suburban sprawl, decaying urban cores, agricultural production that relies on long-distance transportation, and so on. In this light, how can engineering be reimagined as a discipline legitimately and deeply concerned for socioecological welfare? Engineers must critically examine and understand engineering's historical roots and impacts on socioecological welfare as well as grapple with and question current realities in redefining the current engineering paradigm.

A new paradigm subscribes a field or profession to new fundamentals, and changes the methods and applications of the field or profession. Indeed, as Thomas Kuhn argues in *The Structure of Scientific Revolutions* (1962), "the decision to reject one paradigm is always simultaneously the decision to accept another." These changes lead to "a decisive difference in the modes of solution…[and] a change in view of the field…and its goals." Kuhn contends, rightly, that these transformations

[7] In the contemporary world, technological development and investment by the American military can be viewed for the purpose of maintaining the vast empire of American neoliberal influence, just as the British used technologies such as steam engines and telecommunication to consolidate its empire in the Indian subcontinent. Misa (2011) discusses how the British developed steam engines, quinine, railroads and telegraph systems to maintain control over the Indian subcontinent. Baillie (2006) describes how famine in India was worsened because of the development of railroad infrastructure.

are only possible with the advantages of hindsight, and the explicit guidance attained from the outcomes of the paradigm being replaced (Kuhn 1962).

The differences in goals and approaches between paradigms reshape and recast problems (such as climate change and sustainability) differently, leading to fundamentally different outcomes; no two paradigms leave the same problems unsolved (Kuhn 1962). Furthermore, the criteria according to which the outcomes of the two paradigms are evaluated are fundamentally different; the criteria for evaluating the work of the activist engineer lie outside the scope of the current engineering paradigm, making the activist paradigm revolutionary. If the current paradigm is focused on the quarterly profit and liability, the activist paradigm is focused on long-term resiliency. If the current paradigm is based on extractive industry and efficient growth, the activist paradigm is based on modularity, repurposeability, and sufficiency. If the current paradigm is based on reliance on large corporations and capitalism, the activist paradigm must, in large part, be based on community-scale works based on community engagement, democracy, and equality.

From Current Engineering Practice to Engineering Praxis

To effect these revolutionary paradigmatic changes, the activist engineer might employ what Marx (1845 [1976]) and Friere (1970 [2000]) call *praxis*—critical thinking and reflective action upon the world to transform it (Smith 1999 [2011]). According to Riley (2008), praxis draws on the understanding of how engineering work affects communities and the world, and is guided normatively through moral and ethical guidance, which in the activist paradigm focuses on social justice and ecological soundness. Importantly, praxis involves an openness to change. While technical work may be guided by traditional engineering principles and learning,

> no assumptions are made about what the right process to follow is…[p]rocess and product, ends and means, thought and action, the general and the specific, the theoretical and the practical are in constant exchange and dialogue. As we think about answers or solutions or goals for change, the process for getting there may change. As we go about the process, the end goals may change…[Praxis] requires critical thinking and ethical judgment. It is "not merely the doing of something" (Riley, 2008).

In this paradigmatic change, the "existential pleasure" of apolitical and ahistorical engineering is replaced with technical development that applies political, social, and ecological learning from the past and present. Praxis redefines engineering responsibility and creates space to learn from non-technical and alternative knowledge bases, thereby allowing engineers to formulate problems differently, as described below.

Responsibility and Praxis

As has been discussed at length in this journal recently (Michelfelder and Jones 2011; Brauer 2012), contemporary professional engineering ethics codes—such those by the

National Society for Professional Engineering, the American Society of Civil Engineers, the American Society of Mechanical Engineers, and other professional engineering societies—do not provide adequate impetus to engineers to incorporate the specific concerns of social justice, ecological holism, and sustainability into engineering work; these codes instead focus primarily on the safety, health and welfare of the public. (We refer readers to Michelfelder and Jones (2011) and Brauer (2012) for more detailed discussions about incorporating social justice and sustainability into professional engineering ethics codes.) We argue that engineers do and should have more agency to deeply consider social justice and ecological holism concerns in engineering work, and that the activist paradigm imbues a different sense of responsibility and accountability in engineers. Most contemporary engineers who work on large problems work on small parts of a larger whole, and many of engineers are given information only on a need-to-know basis (Martin and Schinzinger 1996). Often, final engineering products and infrastructures are physically removed from the engineers' workplace, lessening the sense of personal accountability and responsibility. The large bureaucracies that engineers work in "diffuse and delimit areas of personal accountability within hierarchies of authority" (Martin and Schinzinger 1996). The frequent pressure to move on to new projects before immediate projects have been operating long enough to observe outcomes carefully also lessens the sense of accountability over the long term (Martin and Schinzinger 1996). In the activist paradigm, instead, an engineer builds strong relationships with places and people. The activist engineer thus follows a piece of technology, from its design to its implementation, studies and weighs the outcomes given an ethic of social justice and ecological soundness, and changes the technological design process accordingly. Praxis transforms the relationship between the engineer and society, holding the engineer more responsible and accountable for her actions.

Engineering Education, Interdisciplinarity and Learning from Other Knowledges

Currently, engineering education does not equip engineers with the knowledge and tools to fully incorporate the often intangible social metrics (Allen et al. 2009) and their interaction with ecological ones (e.g. sentimental attachment to homes and land) into technical problem solving and design, while quantifiable non-technical considerations like economics are seemingly added on to engineering work. Praxis, on the other hand, involves the "deep interdisciplinarity" that Vucetich and Nelson (2010) articulate:

> Deep interdisciplinarity is not represented by, for example, an engineer and an economist working to develop more efficient means of meeting human needs. However, an ecologist researching the ecological effects of biofuel production in coordination with the sociological dimensions of biofuels…[or] an ecologist and an ethicist collaborating to better understand the nature of ecosystem health may be an example of deeply interdisciplinary collaboration…[just like] the collaboration between evolutionary ecologist E. O. Wilson and social scientist Stephen Kellert, which gave rise to the biophilia hypothesis (Vucetich and Nelson 2010).

Through praxis, there is much to be learned from other knowledge bases that have inextricable ties with technological development. For example, the profession of urban planning, which provides the templates for the design of technological infrastructures such as roads, transit systems, energy grids, and water treatment facilities, is founded on principles of social theory. A significant portion of urban planning education is dedicated to learning the history of urban planning, the effects of urban planning on social equality, and planning for organizational and community change. Since engineers actually create and build urban infrastructures, it is absolutely essential that engineers be trained to understand non-technical theory to evaluate socioecological outcomes. Important questions have already been and are continually raised about why past efforts in urban planning have led to inequality, structural poverty, and ecological degradation; engineering's role in these outcomes must be part of the dialogue. The activist paradigm can be inspired by new models of urban gardening, which provide case studies on how alternatives to traditional industrial paradigms directly address problems of climate change while being sensitive to local socioecological conditions. Given the inertia of trying to combat the ill-effects of industrial agriculture—such as decreasing crop diversity, water pollution from chemical fertilizers and pesticides, and long-distance transportation—urban gardening projects have the capacity not only to provide access to fresh fruits and vegetables grown in an ecologically sound manner to one and all, but also have the capacity to remediate brownfields, provide constructive and positive opportunities for at-risk youth, and build neighborliness. Similarly, activist engineering approaches to solving problems must incorporate broader concerns beyond the technical when addressing large problems like climate change.

Problem Definition Through Praxis

In this new activist engineering paradigm, problems are defined not by corporate bureaucracies, lawyers, or businesspeople, but rather they originate from the communities where problems exist, from observing how human actions impact ecosystems, and by deeply considering alternative problem definitions through non-technical knowledge. Instead of constantly trying to engineer large-scale technological solutions like industrial biofuels or carbon capture and sequestration in the face of ever larger problems such as climate change, the activist engineer has the ability to design technological systems to focus on basic requirements and services—such as heating and cooling, lighting, clean water, and mobility, to name a few—that smaller communities of people need, even in the Global North. This approach fundamentally questions the paradigm of large industrialism and structural problems such as reliance on fossil fuels by providing meaningful low-ecological impact and local alternative solutions. Activist engineering does not render claims of social injustice or ecological degradation through technology as illegitimate; rather, the activist paradigm allows the engineer a more detailed view of socioecological interactions by expanding the group of stakeholders—the disenfranchised and impoverished, animal and plant life, non-living parts of ecosystems, and so on—involved in and affected by technological development.

Importantly, activist engineering is not a rejection of technology. A constant reevaluation of process and goals and an understanding of engineering history empower activist engineers to reformulate technological designs and attempts to technologize. Most profoundly, the notion of praxis not only changes the nature of technologies developed, but also raises authentic alternatives to technology such as the radical—and perhaps necessary—possibility of *not* "engineering a solution." This is in some sense analogous to a surgeon who decides not to perform an operation on a patient given the tradeoffs between the risks and the potential outcomes of a surgery. Through praxis, engineers learn about the actual political and social nature of problems and act upon that learning, possibly influencing the demands of the community given direct community involvement in the technical design process, while also creating an environment in which society becomes more and more accepting of engineering with political and socioecological purposes.

Climate Change and Sustainability: Practice Versus Praxis

Climate change—a problem unbounded in space and time—does not fit within the current paradigm (in a Kuhnian sense) of short-term thinking and technological solutions that can be uniformly applied around the world. Climate change has been created by particular socioeconomic and political orders founded on greenhouse gas-emitting technologies—technologies that have been subsidized and bolstered by nation states and corporations (Mitchell 2011)—and current responses to climate change rely on this very order. Climate change is consequently a problem driven by coal- and fossil fuel-based energy technologies, and an outcome of the political and social interests—such as geopolitical wrangling and economic growth—embedded in technological systems and infrastructures (Mitchell 2011).

Climate change represents a system destabilizing (Hughes 1987) problem, and the framing of climate change as a "carbon" problem is "possibly the greatest and most dangerous reductionism of all time: a 150-year history of complex geologic, political, economic, and military security issues all reduced to one element" (Princen et al. 2013). While from a purely physical perspective greenhouse gases are causing climate change, through praxis, it is apparent that addressing the root causes of climate change requires an overhaul of political, economic, and social structures. Climate change is a deeply moral and ethical problem. Through praxis the activist engineer couples technological solutions to climate change with requisite social changes, such as a reduction in large-scale energy consumption and the promotion of locally-based lifestyles that are as necessary if not more so than the technological solutions. We posit that the outcomes of such social changes obviate the need to take the risks of geoengineering (Jamieson 1996) or other large-scale technological solutions to climate change, responses that still envision infinite material growth into the future. Guided by the concerns of social justice and ecological soundness, the goal of activist engineering is to effectively incorporate the concerns of stakeholders such as people whose lands are being lost to rising sea levels, biofuel plantations, and extractive mining for rare earth metals used in alternative energy technologies. For example, Sakellariou (2013) describes how engineers can incorporate procedural justice concerns into siting and building non-carbon dioxide emitting renewable energy technologies in response to carbon dioxide emitting energy sources. Sakellariou (2013) argues that the

> engineer's competency portfolio must consist of (a) acquiring the engineering knowledge that is necessary for building technically sound renewable energy projects; (b) acquiring the knowledge about environmental, political and legal implications of renewable energy project development; (c) acquiring the knowledge regarding renewable energy projects' social justice considerations; and (d) acquiring the knowledge to assess and facilitate community involvement in renewable project development.

Walter and Gutscher (2010) write about how such social justice considerations impact renewable energy infrastructure design in Europe: community concerns around biofuel and wind energy projects tended to reign in the scale and scope of proposed projects to focus on the local and small. The researchers found that according to community residents, not only should the renewable energy projects have minimal impact on the landscape, but also that community residents would support renewable energy infrastructures only if they were maintained by people and engineers from within the community, and if the projects provided heat and electricity for the local community first and foremost (Walter and Gutscher 2010). Solutions to climate change under the activist paradigm are hence not just another turn of the technological crank. Rather, the solutions are founded on an expanded set of decision-making criteria, such as the localism described above, to provide meaningful alternatives to technologies inspired by the contemporary engineering paradigm.

More broadly, by incorporating historical and contemporary political, technological, and social knowledge, the activist paradigm frames climate change differently, and therefore the solutions stemming from the activist paradigm cannot be judged according to metrics from the current paradigm (e.g. increase in gross domestic product per unit carbon dioxide emissions), because the activist paradigm is solving a different problem. The activist paradigm allows non-technological solutions such as "keep them in the ground," as Princen et al. (2013) suggest for fossil fuels. In the activist paradigm, metrics to evaluate the efficacy of engineering work are changed from corporate quarterly profit and material growth into metrics like community resiliency, self-sufficiency, neighborliness, well-being, and equality, thereby redefining the interests of the engineering profession.

Concluding Thoughts

Activist engineers understand how the notions of apoliticism and ahistoricity result in the current engineering practice of offering only technological progress as a solution to any future problem. With regard to climate change and sustainability, activist engineers thus question any work that results in technologies that accept the paradigm of infinite material growth, and that ignore issues of social justice and ecological holism.[8] Employing praxis, activist engineers transform contemporary engineering practice as they are empowered to act on the political and value claims of their work. They thus reframe problems such as climate change and sustainability as socioecological problems that cannot be exclusively addressed as technological problems.

We envision vigorous discussions about how to incorporate praxis into engineering practice. Mary O'Brien (1993) provided her own suggestions for scientists (10 % of your money and 10 % of your time) to work in the public interest, and we find these suggestions readily transmutable to engineering praxis. Engineering praxis can involve learning new knowledge by working on projects and actively engaging with sociologists, urban planners, historians and psychologists or by working with public interest groups; by serving on local, state, or national committees or task forces and lending engineering expertise to community activists, thereby taking a new responsibility for engineering work; by reframing the problems engineers work on by insisting that the public be included in technical decision-making; by creating non-profit engineering groups that move the balance of power away from large corporations and engineering bureaucracies; and by designing technologies that provide impoverished and underserved communities such as those living close to industrial sites with real, timely data, knowledge and knowhow to challenge local municipalities and governments about their living conditions. Praxis thus encourages forms of active engagement outside the sphere of traditional engineering practice, lending a double meaning to the term "activist engineer"—not only does the activist engineer work to promote social justice and ecological holism in the traditional sense of "activism," but the activist engineer also leads by example, taking up causes of their own initiative. While it is practically impossible to envision a mass movement of activist engineers at every level of the profession overnight, we believe strongly that activist engineers are needed urgently at the highest levels of engineering leadership.

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References

Allen, D., Allenby, B., Bridges, M., Crittenden, J., Davidson, C., Hendrickson, C., et al. (2009). *Benchmarking sustainable engineering education: Final report*. Austin: University of Texas at Austin, Carnegie Mellon University, Arizona State University.

Baillie, C. (2006). Engineers within a local and global society. San Rafael, CA: Morgan & Claypool.

Beck, U. (1992). Risk Society: Towards a New Modernity. New Delhi: Sage Publications, translated by Ritter, M. from Beck, U. (1986). Risikogesellshaft: Auf dem Weg in eine andere Moderne. Frankfurt am Main: Suhrkamp.

Brauer, C. (2012). Just sustainability? Sustainability and social justice in professional codes of ethics for engineers. *Science and Engineering Ethics, 19*, 875–891.

Davison, A. (2001). *Technology and the contested meanings of sustainability*. Albany, NY: State University of New York Press.

[8] Hydraulic fracturing for natural gas is a fitting example of how large-scale "clean energy" alternatives to oil and coal still result in social injustice and ecological degradation and do not fundamentally change society to be less energy intensive and materially consumptive.

Florman, S. (1976). *The existential pleasures of engineering*. New York: St. Martin's Press.
Friere, P. (1970 [2000]). Pedagogy of the Oppressed. 30th Anniversary Edition. New York, NY: Continuum Publishing, translated by Ramos, M. B.
Hauser-Kastenberg, G., Kastenberg, W. E., & Norris, D. (2003). Towards emergent ethical action and the culture of engineering. *Science and Engineering Ethics, 9*, 377–387.
Hecht, G. (1998 [2009]). The radiance of France: Nuclear power and national identity after World War II Cambridge, MA: MIT Press.
Hughes, T. (1987). The evolution of large technical systems. In W. Bijker, T. Hughes, & T. Pinch (Eds.), *The social construction of technological systems* (pp. 51–82). Cambridge, MA: MIT Press.
Jamieson, D. (1996). Ethics and intentional climate change. *Climatic Change, 33*, 323–336.
Jonas, H. (1984). *The Imperative of Responsibility. In Search of an Ethics for the Technological Age*. Chicago: University of Chicago Press.
Karwat, D. (2012). On the Combustion chemistry of biofuels and the activist engineer. PhD Thesis, University of Michigan.
Kuhn, T. S. (1962 [1996]). The Structure of Scientific Revolutions. 3rd edition. Chicago: University of Chicago Press.
MacKenzie, D. (1990). *Inventing accuracy: A historical sociology of nuclear missile guidance*. Cambridge, MA: MIT Press.
Martin, M. W., & Schinzinger, R. (1996). *Ethics in engineering* (3rd ed.). New York, NY: McGraw-Hill Companies.
Marx, K., & Engels, F. eds. (1845 [1976]). Collected Works of Karl Marx and Friedrich Engels, 1845-47, Vol. 5: Theses on Feuerbach, The German Ideology and Related Manuscripts New York, NY: International Publishers.
Michelfelder, D., & Jones, S. (2011). Sustaining engineering codes of ethics for the twenty-first century. *Science and Engineering Ethics, 19*, 237–258.
Misa, T. (2011). *Leonardo to the internet: Technology and culture from the renaissance to the present* (2nd ed.). Baltimore: Johns Hopkins University Press.
Mitcham, C. (1994). *Thinking through technology: The path between engineering and philosophy*. Chicago: University of Chicago Press.
Mitchell, T. (2011). *Carbon democracy: Political power in the age of oil*. Brooklyn, NY: Verso Books.
Nixon, R. (2011). *Slow violence and the environmentalism of the poor*. Cambridge, MA: Harvard University Press.
Noble, D. (1977). *America by design: Science, technology, and the rise of corporate capitalism*. New York, NY: Alfred A. Knopf.
O'Brien, M. (1993). Being a scientist means taking sides. *BioScience, 43*, 706–708.
Princen, T. (2012). *A sustainability ethic. Handbook of global environmental politics*. Cheltenham: Edward Elgar.
Princen, T., Manno, J. P. & Martin, P. (2013). Keep Them in the Ground: Ending the Fossil Fuel Era. *State of the World 2013: Is Sustainability Still Possible?* (pp. 161–71). Washington, DC: Worldwatch Institute.
Riley, D. (2008). Engineering and social justice. San Rafael, CA: Morgan and Claypool.
Sakellariou, N. (2013). A Framework for Social Justice in Renewable Energy Engineering. In Lucena, J. (Ed.), *Engineering Education for Social Justice: Critical Explorations and Opportunities. Philosophy of Engineering and Technology 10* (pp. 243–267). Dordrecht: Springer.
Smith, M. (1999 [2011]). What is praxis? The Encyclopedia of Informal Education. http://www.infed.org/biblio/b-praxis.htm. Accessed July 26, 2012.
Tucker, R. P. (2010). Containing communism by impounding rivers: American Strategic interests and the global spread of high dams in the Early Cold War. In J. R. McNeill & C. R. Unger (Eds.), *Environmental histories of the Cold War*. Washington, DC & New York, NY: German Historical Institute & Cambridge University Press.
Vesilind, P. A., & Gunn, A. S. (1998). *Engineering, ethics, and the environment*. Cambridge: Cambridge University Press.
Vucetich, J., & Nelson, M. (2010). Sustainability: Virtuous or vulgar? *BioScience, 60*(7), 539–544.
Walter, G., & Gutscher, H. (2010). Public acceptance of wind energy and bioenergy projects in the framework of distributive and procedural justice theories: Insights from Germany, Austria and Switzerland. http://www.advisoryhouse.co.uk/UserData/Publication_00685_00.pdf. Accessed December 13, 2013.
World Commission on Environment and Development (1987). Our Common Future. United Nations Documents.