Life-centered Design – A Paradigm for Engineering in the 21st Century

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Abstract

The engineering field, particularly engineering education, is in need of a new paradigm. We need a vision of engineering that encompasses traditional technical competence with the enlarged scope of social responsibility and ecological awareness. There have been significant developments in this direction, including the concept of sustainability, the latest engineering accreditation outcomes, ethics canons in some engineering disciplines, the field of industrial ecology, and the concept of biomimicry. Yet it is unlikely that incremental curricular changes can provide for engineers that are broadly educated, socially responsible, and ecologically grounded. This paper presents a vision for a new paradigm for engineering, starting with sustainability but going beyond it to emphasize improving the world. This vision is captured with this foundational ethic: ***Engineers shall hold paramount the improvement of both human life and the larger community of life, for present and future generations.*** This paper develops this life-centered engineering vision by reviewing recent developments and their potential to transform engineering education and engineering practice.

Introduction

Does engineering need a new paradigm? What is the current engineering paradigm? What are the founding principles of our current paradigm? What's the new paradigm look like and what does it mean for education?

The answer to the first question is clearly yes, as I will show through a description of this new world view that more correctly models the modern world. The new world view I present applies to all engineers, even though it is certainly not accepted yet by most engineers. This paper, then, presents an alternative lens through which to understand the world and see the route that we must take.

Engineers' Current World View

We see our role as problem solvers and believe that nearly all problems can be solved, typically by breaking the problem down into smaller pieces. We also tend to see the world as black and white, that if people understood the "facts" of the situation, only one answer is possible. Similarly, we base most of our decisions on analysis of these facts, tending to neglect factors that cannot be readily quantified. We have faith in economics to guide our designs. It is not our job to decide what should be made; we are responsible for getting it made in an economical way.

We believe that the work of engineers to single-mindedly develop and deploy technology will continue to make life better, i.e., we believe in real human progress facilitated by our work.

There are a lot of good things to be said about this paradigm, or at least the consequences of it. It has enabled modern society, at least the rich, industrialized societies of the world, to live in an unprecedented time of material affluence. People also live longer healthier lives.

But over the last several decades, we have learned that technologies often have unintended negative consequences, with significant impact on society. Technology has contributed to many of our problems today – nuclear weapons, resource depletion, pollution, global warming, the ozone hole, soil erosion, and species extinction. Technology is also implicated in societal changes like geographic dispersion of families and the nature of work. A reductionist and isolationist approach to problem solving cannot account for the complex ways technology affects the world. We must approach problems more holistically, by increasing our own understanding of other disciplines and by working more closely with other disciplines. In general, it means taking more responsibility for the effect of our work on the world, and ensuring it leads to real progress.

Just as we engineers are not single-handedly responsible for the problems associated with technology, we will also not single-handedly solve these problems. Our entire culture is implicated. But there is a lot that engineers can do to make positive change. We can take a leadership position through developing a new paradigm that better reflects the modern world.

An Emerging World View

The new paradigm I'll describe is already evident to some extent in certain engineering disciplines and in the recent literature, including the new accreditation criteria, but it has not yet been adopted comprehensively nor in its most visionary sense.

Ecology has taught us that the world is all about connections and is an incredibly complex web of systems and subsystems, both living and nonliving. If we ignore or misunderstand these connections, then at best our designs are suboptimal, and at worst are dangerous and life threatening. Emphasis on a piece of a problem can obscure the bigger picture. All of human activity takes place within this larger realm of Earth's living systems. Classical economics, once the accepted framework for engineering, is also guilty of neglecting the value of living systems, particularly the services they provide like clean water and clean air. As Lester Brown points out in *Eco-Economy*: "Economists see the environment as a subset of the economy. Ecologists, on the other hand, see the economy as a subset of the environment."¹

As humans, we have our own systems that add further to the complexity of living. These political, societal, and ethical systems have direct bearing on technology, providing both limits and direction. As technologists we cannot ignore the relevance of these systems to our everyday work, and our college educations should better prepare us to understand human systems and to work cooperatively with people from these other disciplines.

Engineers need to get beyond the reliance on rational thinking and the idea that most problems are black and white and amenable to one best technical solution. Most problems are much more

thorny than that because what we engineers help to create affects people and the rest of the world. Engineers typically overestimate the role of quantification and rationality in decision making, as well as thinking that because they understand the physical world better than most people, they have the really important knowledge in a given situation. We need to teach engineers to understand people better, work effectively on teams, and participate in the political process. We need them to understand ecology and systems analysis.

These ideas are somewhat reflected in the Accreditation Board for Engineering and Technology's (ABET) Criterion 3 Program Outcomes and Assessment (relevant outcomes in bold italics)²:

Engineering programs must demonstrate that their graduates have:

- (a) an ability to apply knowledge of mathematics, science, and engineering
- (b) an ability to design and conduct experiments, as well as to analyze and interpret data
- (c) an ability to design a system, component, or process to meet desired needs
- (d) ***an ability to function on multi-disciplinary teams***
- (e) an ability to identify, formulate, and solve engineering problems
- (f) ***an understanding of professional and ethical responsibility***
- (g) an ability to communicate effectively
- (h) ***the broad education necessary to understand the impact of engineering solutions in a global and societal context***
- (i) a recognition of the need for, and an ability to engage in life-long learning
- (j) ***a knowledge of contemporary issues***
- (k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

While outcomes d,f,h and j are related to this ecological, holistic world view, they are a statement about what is to be measured, they are not a focused vision. They give us an indication that education is already directing their efforts consistent with a new paradigm.

At Penn State in 1994, our Leonhard Center for the Advancement of Engineering Education put forth a vision of the World-Class Engineer, see www.engr.psu.edu/LeonhardCenter/eec/wce.htm. They have identified six characteristics of a World-Class Engineer:

1. Aware of the world
2. Solidly grounded
3. Technically broad
4. Effective in group operations
5. Versatile
6. Customer oriented

These are all excellent qualities, and they reflect much of what was discussed above. I'm especially encouraged by the characteristic "solidly grounded." This is described to mean:

- thoroughly trained in the fundamentals of a selected engineering discipline

- has a historical perspective and remains aware of advances in science that can impact engineering
- realizes that knowledge doubles at breakneck speed and is prepared to continue learning throughout a career.

My problem with this grounding is that it does not speak to the purpose of engineering. What is our vision of our role in society? In life? To emphasize fundamentals of an engineering discipline provides no grounding to me, unless that is implicit in the fundamentals of a discipline, which it isn't.

I am not the only one to notice this lack of vision among engineers. Langdon Winner, in *The Whale and the Reactor*, begins the book by criticizing technology and technologists for appearing “unaware of any philosophical questions their work might entail.”³ He goes on to say:

“As a way of starting a conversation with my friends in engineering, I might sometimes ask, ‘What are the founding principles of your discipline?’ The question is always greeted with puzzlement. Even when I explain what I am after, namely, a coherent account of the nature and significance of the branch of engineering in which they are involved, the question still means nothing to them. The scant few who raise important questions about their technical professions are usually seen by their colleagues as dangerous cranks and radicals. If Socrates’ suggestion that the ‘unexamined life is not worth living’ still holds, it is news to most engineers.”

Indeed, when I ask new engineering students, “What is the purpose of engineering?” their first reaction is “I don’t get it.” When pressed, and after doing some research on the internet, their most common answers are to improve efficiency, to reduce costs, or to make life easier. Sometimes they recognize these answers as various characteristics of what we call *progress*. While these answers seem to be somewhat superficial, I think they reflect the prevailing attitudes of engineers. We are just not challenged in our education or our practices to reflect any deeper on the relationship of our work to society or life in general. Many students report that they enter engineering for two main reasons – they are good at math and science, and the pay is good.

Was it always this way? Samuel Florman, in *The Existential Pleasures of Engineering*, says that up until about 1950, “The conventional wisdom was that technological progress brought with it real progress – good progress – for all of humanity, and that the men responsible for this progress had reason to consider themselves heroes.”³ Between 1850 and 1950, what Florman calls “The Golden Age of Engineering,” engineers took delight in “thinking about themselves as saviors of mankind.”

Since the lot of the common man had traditionally been one of unrelenting hardship, engineers looked upon their works as man’s “redeemer from despairing drudgery and burdensome labor.” Once the common man was released from drudgery, the engineers reasoned, he would inevitably become educated, cultured and ennobled, and this improvement in the race would also be to the credit of the engineering profession. Improved human beings, of course, would have to be happier human beings.

What is interesting about Florman's analysis of this "Golden Age" is that the engineers of this era, like many engineers today, did not necessarily consider the social, cultural, and environmental aspects of their work. What was different then is that the larger culture also bought into this vision. People in the industrialized countries did indeed experience significant material progress, and much of the drudgery of day-to-day life was reduced. Popular culture generally believed that real human progress was being achieved, and that engineers were greatly responsible for that progress.

Florman claims that what changed in 1950 was the project to develop the hydrogen bomb. People now faced the potential of a technology so powerful that it could destroy all of life. Then in the 1960's came the environmental movement followed by the countercultural critique of the dehumanizing effects of technology. Underlying these new sources of discontent with technology and engineers is the realization that the material comforts and reduced drudgery brought about by engineering have not brought about the anticipated superior human beings, plus we live with potentially serious unintended consequences.

It might be accurate then to say that the founding principle for engineers of this Golden Age was that of *progress through technological development*. But now we know that we must be more careful about the nature of new technologies. More is not necessarily better. Our knowledge about consequences and our ability to build this into our engineering is growing all the time. But we still seem to have no collective vision that we can respond to and be inspired by.

Sustainability

The principle that can begin to provide us with that vision is sustainability, defined in the Brundtland Report as *the ability to meet the needs of the present without compromising the ability of future generations to meet their own needs*.⁵ This concept has one distinguishing new feature: it addresses the responsibility of this generation to future generations. It recognizes that what we do today can have profound impact on the world of tomorrow. It is not discipline specific but transcends all of engineering, all of human activity. It makes a good starting point for a new engineering paradigm but it needs further elaboration to be useful.

An important observation to be made about sustainability as a founding principle for engineering is that this principle is essentially an ethic. It implies that sustainability is a good goal and that we generally agree on it. Like ethics, it is not an add-on issue that is only applicable in a few instances, but it is imbedded in the practice of engineering. To me it is the beginning of that solid foundation we need for engineering.

One way to begin to picture what sustainability means is to consider that sustainability must be assessed by three aspects, pictured in Figure 1 as three legs of a triangle. A sustainable approach must be successful at addressing all three of these aspects. Companies have begun to recognize these three aspects of sustainability as a "triple bottom line."⁶ Bill McDonough recommends further that they become a "triple top-line," pointing out that they need to be considered at the very start of design. In other words, he argues that they are foundational; they are the context in which we work.

Let's look at the environmental aspect for a moment. In this context, sustainability directs us to consider the use of resources, the creation of pollution, and damage to natural capital. A simplistic look at resources suggests that we must eventually eliminate depletion of nonrenewable resources, and make full use of renewable resources. Those resources that are nonrenewable must be reclaimed from products at the end of their life cycle, and incorporated into new products. This concept is in accord with the natural principles of cycles and "waste" from one organism being food for another, i.e., there is no net waste. Matter that is released into the environment must be able to be assimilated into that environment within its carrying capacity (even an excess of organic nutrient can be bad for the environment). As engineers, we have a lot to say about what materials are used, how products are manufactured, and how they can be designed to be reclaimed at the end of their useful lives to be made into new things.

Figure 1 The three aspects of sustainability

My greatest concern with sustainability is that it is difficult for engineers, and people in general, to see it as something to rally around. It doesn't come close to the vision of progress as making a better world wherein life flourishes. Can we get excited about meeting our needs? I think what we really want is sustainability as a minimum requirement with continual progress as human beings. Furthermore, we must acknowledge our obligation to the larger community of life that provides both resources and services for our lives, as well as beauty and spiritual nourishment.

I propose a more positive principle as a foundation for engineering, one that implies sustainability:

Engineers shall hold paramount the improvement of both human life and the larger community of life, for present and future generations.

The term *improvement* was chosen to ensure that quality of life issues are considered. Improvement does not necessarily mean a growing economy, or greater material affluence, nor does it exclude them.

This principle goes well beyond the first canon of the Code of Ethics of the National Society of Professional Engineers: "Engineers, in the fulfillment of their professional duties, shall hold paramount the safety, health, and welfare of the public."⁷ It holds up the progressive goal of improvement, it recognizes the larger community of life, and it connects us to the future.

Signs of Change

ASCE Code of Ethics

One of the engineering organizations that is a leader in sustainability is the American Society of Civil Engineers (ASCE). In 1996, ASCE amended its code of Ethics by including in the Fundamental Canons that "Engineers shall hold paramount the safety, health, and welfare of the public and shall strive to comply with the principles of sustainable development in the

performance of their professional duties.”⁸ Under the Guidelines to Practice for the Fundamental Canons, it states that “Engineers shall be committed to improving the environment by adherence to the principles of sustainable development, so as to enhance the quality of life of the general public.” In June, 2001, ASCE updated its policy statement on the “The Role of the Engineer in Sustainable Development.” Included is the following:

“Sustainable development is the challenge of meeting human needs for natural resources, industrial products, energy, food, transportation, shelter, and effective waste management while conserving and protecting environmental quality and the natural resource base essential for future development.

Engineers should:

- Cultivate a broader understanding of political, economic, technical, and social issues and processes related to sustainable development.
- Acquire the skills, knowledge, and information to facilitate a sustainable future.
- Develop the tools required to achieve sustainable integration of the environment and development, together with other scientists and practitioners.
- Develop economic approaches that recognize natural resources and our environment as capital assets.
- Move beyond their disciplines to evaluate alternatives and to effect policy changes toward sustainable development.
- Develop project teams with other design professionals, economists, and physical scientists to arrive at sustainable solutions.
- Adopt and apply an integrated systems approach for project decisions in which costs, benefits, and effects on sustainability are considered for the whole lifetime and enduring effects of the project.
- Work cooperatively with other trade and professional organizations that are focused on this issue to minimize duplication and bring the greatest resources to bear on advancing sustainability.
- Utilize life costing in projects, which includes the associated environmental costs.”

This entire passage is included because it represents an excellent list of actions that engineers should take, and it reflects many of the points made earlier. It should be used to reflect on curricular changes that would provide the education of such an engineer.

Industrial Ecology

Eloquently explained by Graedel and Allenby in their book, *Industrial Ecology*, this new field comes closest to comprehensively describing ways to achieve sustainability in our technological activity.⁹ Graedel and Allenby present three complementary definitions of industrial ecology. The first one has the most specifics:

Industrial ecology is the means by which humanity can deliberately and rationally approach and maintain sustainability, given continued economic, cultural, and technological evolution. The concept requires that an industrial system be viewed not in

isolation from its surrounding systems, but in concert with them. It is a systems view in which one seeks to optimize the total materials cycle from virgin material, to finished material, to component, to product, to obsolete product, and to ultimate disposal. Factors to be optimized include resources, energy, and capital.

Their third definition is the most visionary:

Industrial ecology is the science of multiscale planetary stewardship, involving the practice of intelligent oversight of the planet as it undergoes natural and anthropogenically driven variability.

They explain that one of most important principles of industrial ecology is the rejection of the concept of waste, a principle based on ecology. This principle is profound and necessary for at least two reasons. One is that eliminating waste and focusing on cycles is ultimately the only sustainable approach, as all resources are finite, as is the ability of the environment to accommodate waste. The second and more important reason is that the principle derives from nature. It refocuses our attention to the natural world as the basis for human activity. Only processes that fit into the larger web of life make sense in the long run.

This grounding in biology and ecology is particularly poignant for engineering educators and administrators because our current engineering curricula emphasize the physical sciences, not the life sciences. While some programs, like Agricultural Engineering, Bioengineering, and Environmental Engineering require courses in biology, very few programs require ecology education. How can we expect our new engineers to incorporate ecological thinking into their engineering without even one course?

Graedel and Allenby also present four Grand Objectives:

1. Maintaining the existence of the human species
2. Maintaining the capacity for sustainable development and the stability of human systems
3. Maintaining the diversity of life
4. Maintaining the aesthetic richness of the planet

Eco-effectiveness

In *Cradle to cradle*, Bill McDonough and Michael Braungart list the three principles of what they call “The Next Industrial Revolution:”¹⁰

1. Waste = Food
2. Use solar income
3. Respect diversity

They refer to this new goal of human activity as being grounded on what they call “eco-effectiveness.” Eco-effectiveness is based upon modeling human activity and designs on nature. They point out that while efficiency has its place it often boils down to “being less bad.” In some cases it sanctions continuing to use up resources and to pollute, plus it provides no inspiring vision of good design. By practicing design using the three principles from above, they

believe that we can take delight in our products, and that they can replenish, restore, and nourish the rest of the world.

I have put together a figure that captures some of the ideas in *Cradle to cradle*, see figure 2. This view puts all of matter ideally into two cycles, or metabolisms. There is the technical metabolism on the left, wherein materials are recycled back into industrial goods. On the right is the biological metabolism, or the biosphere. The goal is for all of the products and materials manufactured by industry to safely feed these two metabolisms, thereby eliminating waste. Recognizing that this may not ever be perfectly achievable, particularly in the short term, because some materials are too hazardous, there is a category of *unmarketables*. These are materials that must be safely stored until we develop ways to detoxify them. Ultimately the goal is to have no unmarketables. Another principle illustrated here is that of using current solar income as the only natural and sustainable energy source.

Figure 2 The two metabolisms involved in eco-effectiveness

Biomimicry

In her book, *Biomimicry*, Janine Benyus describes this new vision, in contrast with the Industrial Revolution, as being “based not on what we can *extract* from nature, but on what we can *learn* from her.”¹¹ It too is based on an ecological view of life, with emphasis on the potential for us to learn from nature how to build our systems so that they fit in. Benyus examines several different projects that exemplify biomimicry, from analyzing how spiders manufacture a waterproof fiber five times stronger than steel from digested insects, to studying how electrons in a leaf cell convert sunlight to fuel.

Biomimicry extends the idea of basing our human activity on ecological principles, to actually modeling our systems on living systems. It represents a move from dominating and devaluing nature to partnering with her.

Engineering Education

So how do we go about teaching students to ***hold paramount the improvement of both human life and the larger community of life, for present and future generations?*** First and foremost,

we must agree that this is the foundational principle for engineering. Then we need to have lively and provocative discussions to begin to flesh out good ways to educate new and practicing engineers to appreciate and incorporate this principle into their work. The ecological thinking behind this principle – life-based, systems oriented, and complex – is a new approach to engineering problem solving. Engineering educators will need to work closely with other educators in biology, ecology, economics, and sociology in this process of change.

There are two significant changes that should take place in the near term. One is to require all engineering students and faculty to be educated in biology and ecology, and to integrate these topics into the engineering curriculum, similarly to the approach for integrating ethics. Two is to involve students in projects that have multidisciplinary teams engaged in applying these concepts in a more integrative way.

With regard to curricular integration of ecological principles, a good starting point is industrial ecology. This field has already encompassed many of the principles discussed here, especially the techniques for better consideration of environmental effects along with economics. Concepts and tools like design for environment, more generally, design for X, and life cycle analysis are important skills for engineers. But this is only the first step. Let the discussion begin.

We need a foundation for engineering that speaks to the place of engineering in the larger scheme of things. A life-centered, all-of-life-centered, principle provides that foundation.

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