The Philosophy of Engineering and the Engineering Worldview

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Abstract

The philosophy of engineering is, in the first instance, concerned to make sense of what we do and how we do it as agents in the world. It is also concerned with understanding the nature of inquiry and exploration in the engineering enterprise. In these latter concerns the philosophy of engineering constitutes the more general framework for understanding the nature of reality and the role of engineering in it. The philosophy of engineering and the engineering worldview supersede and subsume the philosophy of science and the scientific worldview.

Introduction

The philosophy of engineering is, in the first instance, concerned to make sense of what we do and how we do it as agents in the world. It is also concerned with understanding the nature of inquiry and exploration in the engineering enterprise. In these latter concerns the philosophy of engineering supersedes and subsumes the dominant 20th Century logico-mathematical philosophy of science.

The philosophy of engineering conceives of the engineer and the engineering enterprise quite broadly. Engineers understand themselves as problem solvers and ‘the problem’ to be solved is the problem of design. For instance: How should we design the irrigation of our fields? How should we design our houses? How should we design tools for these tasks? How should we design our neighborhoods and our cities? How should we design our economy? Tariffs or not? How should we design our political system – to preserve and defend our economy and our neighborhoods? How should we design our inquiries – the research and development activity of our society? The engineer, so conceived, is not merely a toolmaker or a creator of novel, useful artifacts. The engineer is equally a system designer, and a system developer.

Another crucial aspect of the proper engineering self-conception is that the engineer has the ability to alter the scientifically expected course of events. Indeed, the engineer has the ability to alter the structure and operation of reality. In practice, of course, this ability is always limited by current capacities and competencies.

As a natural extension of the philosophy of engineering, the engineering worldview considers what the world must be like if the engineer is doing and is able to do what he thinks he is doing and able to do. The engineering worldview is a developing understanding of the place and role of the engineer and the engineering enterprise in the universe. Clearly the engineering worldview differs considerably from the scientific worldview – the latter being that of a mechanically deterministic eternal clockwork studied by means of the classical, 20th century, logico-mathematical philosophy of science.

The 20th century philosophy of science was never self-referentially coherent. The philosophy of engineering is a broader, more comprehensive, self-referentially coherent view of ourselves (viz. as engineers) and our place in the universe. Capturing the more general context, the philosophy of engineering supersedes the limited perspective of the philosophy of science. Similarly the engineering worldview is able to understand and subsume the successes of mechanical theories, seeing them as limited special cases within the more general framework of the universal engineering enterprise.

The move to the correct, self-referentially coherent philosophy of engineering requires a Paradigm Shift, and as such can only be arrived at through a series of critical reflections on the limits of philosophy of science. Similarly the correct, self-referentially coherent engineering worldview is found through critical reflections on the limits of the scientific worldview. The reason it has been so difficult to advance beyond the rather obvious inadequacies of the classical philosophy of science and scientific worldview is that there is no simple reasoning from within these existing paradigms that can lead to a conceptually revolutionary, more general, superseding paradigm. You cannot reason from the experience of the limits of science – in scientific terms – to the superseding engineering framework. Even though the later, more general conceptual framework, can understand the successes of the earlier – albeit in a conceptually new way – the paradigm shifts to the more general understanding is, nonetheless, conceptually discontinuous.

The inadequacies of the dominant 20th Century Logical Positivist philosophy of science were pointed out by Sir Karl Popper (1935; 1965), Thomas Kuhn (1963), Paul Feyerabend (1978) and Imre Lakatos (1965) among others.

Engineers Samuel Florman (1994) and Walter Vincenti (1995) pushed from the other side insisting that engineering was not 'merely' applied science and could not be understood within the scientific framework. Henry Petroski (2010) has recently argued that all inquiry, even what been thought of as pure scientific inquiry, can only be properly understood within the engineering framework.

American Pragmatist John Dewey (1930) usefully contrasts the philosophy of science and the philosophy of engineering as alternative representations of real inquiry, characterizing them correspondingly as the Spectator and the Participant representations.

The Spectator Representation of Inquiry

In the spectator representation, inquiry is intent on discovering the objective nature of reality. Advances converge to the final theory of everything, a complete and consistent correspondence where theory matches objective reality (Barrow 1991). This conception of the enterprise of inquiry entails, indeed requires, a certain conception of reality (viz. the scientific worldview). In order for such an inquiry to be successful and to converge to reality, the nature of reality must remain constant. If the nature of reality were changing, perhaps randomly, convergence would be impossible. The spectator representation tacitly assumes that the nature of reality, the order governing all the phenomena of the universe, is invariant over time. The spectator representation also entails that our activity as inquirers doesn't alter the nature of reality. If our activity as inquirers were to alter the nature of reality then the possibility of convergence to a fixed, timeless objective reality would be lost.

The Participant Representation of Inquiry

The participant representation of inquiry, which I identify with philosophy of engineering, immediately accepts that the activity of inquiry alters the nature, structure and operation of reality. This worldview precludes any ultimate convergence to the spectator's hypothesized time-invariant, objective, inquirer-independent reality. Engineers naturally imagine they can and do alter the course of events. The participant-engineering representation entails that engineering research, development and deployment progressively re-organizes the way the universe works. Articulating the consensus, Nobel Laureate Herbert Simon (1981) argues that engineering is problem solving and that problem solving is 'attempting to move from a current state of affairs to a more desirable future state of affairs'. Real problem-states are opportunity-states where alternative futures and alternative solutions are possible. The potential futures are embodied in the engineer and the situation. The engineering solution-state is conceptually different from the engineering problem-state. The conceptual difference is a qualitative difference – logico-mathematically discontinuous. A solution-state, as a more desirable future is fully determined by the problem or opportunity-state. The Participant Universe – per hypothesis, the engineering universe – must have a qualitatively emergent (viz. problem solving) history.

From Philosophy of Science toward Philosophy of Engineering

There were at least two separate lines of criticism in philosophy of science that point toward philosophy of engineering (Ayer 1978). One is associated with Thomas Kuhn and the other with Karl Popper.

It is helpful to grasp that the Logical Positivist representation of scientific inquiry as logico-mathematical followed quite reasonably from one of the founding presuppositions at the beginning of modern science. Galileo, reaffirming the ancient Pythagorean thesis, argued that the language of nature was mathematics. The Positivists argued that mathematics was based on logic, so the order governing reality should be thought of as logico-mathematical. The subsequent dramatic successes of the Newtonian research program strongly supported the implicit scientific hypothesis: that all phenomena in the universe are governed by one universal logico-mathematical order. For the Positivists 'it stood to reason' that the successful method of inquiry (viz. scientific method) must be logico-mathematical. In other word, if the universe is governed by a logico-mathematical order, then the path to a complete comprehension of that order must be a logico-mathematical scientific method. The popularity of the logico-mathematical philosophy of science led many, including Stephen Hawking (1988) to suggest that scientific inquiry could be, and soon would be, turned over to logico-mathematically programmed mechanical computers.

Thomas Kuhn tried to make sense of the actual history of scientific inquiry according to these Logical Positivist expectations. According to the Positivist's conception of successful inquiry there should have been conceptual continuity. The relation between earlier and more advanced scientific theories should have been logico-mathematical. Kuhn came to argue against the Positivist conception, maintaining that the evidence of the history of science forced him to conclude that literally all the major advances in the history of science were logico-mathematically discontinuous – conceptually revolutionary. The earlier and later theories were incommensurable, meaning that later theories were not just extensions of the earlier theory. Feyerabend and Lakatos, in support of Kuhn, argued that if we actually learn something then later understandings must be qualitatively, conceptually, different from the earlier ones. Kuhn argued that even with considerable counter-evidence pointing to the inadequacies of an earlier theory, there was no way to logically reason to a more advanced theory.

In his relentless critique of the Logical Positivist representation of inquiry, Kuhn began to articulate the characteristics of actual inquiry. Most importantly he saw inquiry as problem solving and as genuinely exploratory and experimental. Along the same lines, Feyerabend argued against the idea that there was one universal scientific method. This idea was equivalent to denying that there was one time-space invariant path to learning to the solution to all possible problems.

The second major line of criticism of the Logical Positivist representation of inquiry is associated with Popper. The most recognizable theme associated with Popper is that all meaningful scientific theories must be falsifiable. Popper's concern had been to distinguish real science from pseudo-science. He noticed that what he took to be pseudo-scientific research programs had a habit of trying to explain away counter-evidence by giving after-the-experimental-failure accounts of why the failure didn't count against the theory. Explaining away typically appealed to extenuating circumstances or unexpected interfering factors. These after-the-fact responses came to be codified in the literature as auxiliary hypotheses. Frustrated by these endless defensive excuses, Popper reasoned that for any legitimate (viz. truly scientific, self-critical) research program should be able to articulate prior to an experiment or, indeed, prior to any and all possible experiments what evidence, if it were to occur, would lead the proponents to abandon the core hypothesis defining their research program. The demand can be called, Popper's Question: what evidence, if it were to occur, would lead you to abandon the core defining hypothesis of your research program (Popper 1963).

However, it quickly became apparent that many legitimate scientists, rather than answering Popper's question, employed these defenses of their core hypotheses. Lakatos offered a thought experiment where a well-confirmed theory of planetary motion encounters unpredicted behavior of the outer planet. Does the legitimate scientist simply abandon the theory? Such an expectation came to be called naïve falsificationism. Rather, Lakatos suggests that his scientist offers an auxiliary hypothesis that there is another previously unknown planet in an outer orbit that is disturbing the known outer planet. The scientist calculates the expected position of the newly hypothesized unknown outer planet, and points a telescope to the position. When no planet is detached, the scientist then offers another auxiliary hypothesis that there is a dust cloud blocking the telescopic view and convinces NASA to send a space probe out to observe, avoiding the dust cloud. Several years later the results are in. Oops! The space probe didn't see any new planet. Still committed to the core hypothesis of his theory of planetary motion the scientist reasons that there must be some sort of electro-magnetic interference with the space probe. Outer space is known to be a hostile environment. He proposes yet another space probe, and so on. The lessons of Lakatos's thought experiment are that scientists use auxiliary hypotheses quite regularly and that such use is quite legitimate – noting that any one of the auxiliary hypotheses might have been successful. Lakatos introduced the notion of a research program to capture how a series of improving theories, as in the planetary example, can be thought of as based on the same general core defining theory of planetary motion. Another lesson is that it is unclear just how long this rationalizing defense of a core hypothesis can reasonably continue. (For an illustrative case study of an ongoing research program, see my treatment of 'Dark Matter' (Bristol 2015).)

Given that legitimate scientific inquiry frequently uses auxiliary hypotheses, Popper's insistence that all meaningful theories must be falsifiable, takes us beyond naïve falsificationism, to a deeper understanding of Popper's Question. Legitimate, self-critical research programs, according to Popper, should be able to state, to articulate, what evidence, if it were to occur, would lead the proponents to abandon the core hypothesis. Any proponents should be able to specify – here and now, in this universe – how one would be able to falsify the core hypothesis. This prior specification, and falsifiability, is only possible if in fact the core hypothesis is *actually* false in this universe. The entailment is that all meaningful, falsifiable theories must *actually* be false. What is meant by 'false' here is simply 'incomplete', conceptually incomplete.

Even highly successful theories incorporate idealizations, and consequently, they are technically false, in the sense of being conceptually incomplete. Unexpectedly, the incompleteness turns out to be demonstrated by evidence that, by its very nature, cannot be conceptually made sense of in terms of the conceptual apparatus of the original core hypothesis.

What I refer to as the surprising answer to Popper's Question' is that you can't articulate the falsifying evidence from *within*, or in terms of, the conceptual apparatus of the core hypothesis in question. What Popper's Question is asking for is a *type* of evidence that cannot possibly be made sense of in terms of the research program defining the core hypothesis.

The surprising answer to Popper's Question means that for every meaningful, falsifiable theory there must be some conceptually discontinuous phenomenon in *this* universe. That same falsifying phenomenon can then presumably be understood as confirming an equally meaningful, falsifiable complementary theory.

The Kuhnian and Popperian lines of argument both point to the inadequacy of the spectator representation of inquiry and learning. The arguments and historical evidence for the limits of this classical, Logical Positivist philosophy of science call for a more general, superseding representation of inquiry. However, as Kuhn's historical studies demonstrate, a theory plus counter-evidence to that theory does not automatically produce a superseding theory. The advance from one theory to a superseding is non-linear. The later theory is conceptually discontinuous with the earlier. One meta-lesson is that one can experience the limits of a research program while remaining in that research program.

As a student working with Popper, Feyerabend and Lakatos it gradually dawned on me that they weren't arguing *from* a theoretical position. Rather, through their increasingly penetrating and sophisticated critiques, they were backing into and toward an emerging new, more definite understanding. The meta-lesson is that new superseding paradigms only emerge gradually through a gradual, recursive and cumulative critical process.

The critique of the Positivist representation of inquiry led us gradually toward a More General Theory within which all meaningful falsifiable theories are understood to be naturally, conceptually incomplete. All successful theories are limited special cases, idealizing selections of limited aspects of reality. The More General Theory must be able to make sense of all possible purportedly scientific theories – but in a new way.

Both Kuhnian and Popperian critiques supply us with clues to a post-scientific, More General Theory. Kuhn establishes that learning is non-linear and involves conceptual revolutions. Our conceptual understanding of reality develops qualitatively. Kuhn argues that since learning is not logical, learning is problematic. Advances in understanding are solutions that cannot be simply reasoned from the prior understanding.

Another way to capture the practical sense of Kuhn's conceptual discontinuities can be seen in the common experience of researchers when they make an advance. Although there is a sense of having converged on the solution, there is an equal and often more powerful sense that the advance has opened up new questions. Qualitatively new types of questions can be formulated in the more advanced, superseding theory that could not even have been formulated in the prior conceptual understanding. Kuhn's 'conceptual discontinuities' are here represented as a consequence of the fact that learning is conceptually emergent and expansive. This process sounds a lot like the way things work in engineering design.

There are several important clues to the nature of the post-scientific More General Theory. First, all meaningful theories, by their very nature, must be incomplete (viz. falsifiable). Any falsifiable theory must be unable to make sense of at least some type of demonstrable phenomena in this universe. There must be at least one complementary, meaningful and falsifiable theory for every potentially successful theory. As Lakatos pointed out, the very process of formulating a scientific theory involves a bias, making a choice. The observer selects one way of experiencing reality, using one type of paradigmatic experimental setup, rather than others. Lakatos argued therefore that every theory has evidence against it even at the moment of theory formation.

In his later writings Popper argued that all learning was problem solving, suggesting a progressive evolutionary epistemology. Since the process of learning is embodied as an irreducible aspect of reality, Popper seems to favor a participant representation of inquiry in a progressively emergent, evolving universe, a kind of research and development worldview that is characteristic of engineers and engineering.

From the Scientific Worldview toward an Engineering Worldview

The arguments and evidence supporting the thesis that the engineering worldview constitutes a More General framework subsuming the traditional scientific worldview arose with the new physics at the beginning of the 20th century. The realization that there couldn't be a common conceptual foundation for the highly successful Newtonian and Maxwellian research programs (Carroll 2010) forced the embrace of complementarity (Bohr 1932; 1956). The particle in the Newtonian framework is conceptually discontinuous with the wave of the Maxwellian framework. Complementarity implies that the participant-inquirer is encountering a universe that is not governed by one universal, objective order that uniquely determines all subsequent states. Complementarity entails that the future is under-determined by the present. The emergence of the actual future requires a choice. Remaining within the classical framework this is often represented enigmatically as the collapse of the Schrödinger wave-function. This choice collapses of the options of the possibility space. The observer's active choice is to implement one type of experimental setup rather than others possible. That choice is, by its very nature, scientifically arbitrary. It has no objective mechanical determinant. These limiting characteristics of the classical scientific worldview illuminated in the new physics generated the search for a More General, superseding, post-scientific, post-objectivist representation of inquiry and parallel understanding of reality.

Critical reflection points out that the choice entailed by quantum complementarity is, by its very nature, scientifically problematic. The choice, literally, cannot be made sense of within the framework of the deterministic scientific hypothesis. However, in the framework of the philosophy of engineering complementarity is embraced and the choice is naturally understood as the active embodied ability of the participant engineer acting in the world.

In the engineering worldview, the problematic character and associated uncertainty of the choice is not only retained but also newly understood as the irreducible experimental and exploratory aspect of all engineering enterprises. It is this genuinely problematic and qualitative character of the choice that makes engineering solutions emergent.

The spectator to participant paradigm shift can be represented as a problem shift. In the scientific framework the detached, spectator's problem of inquiry is to understand how the world works – objectively, independent of the inquirer – with no anticipation of practical benefit. In contrast in the engineering framework the participant's engineering problem is how to work in the world – how to problem solve, how to move, practically and beneficially, from a current state of affairs to a more desirable future state of affairs. Where the scientific worldview struggles and can only represent the choice as arbitrary, the engineering worldview understands the decision as a free choice between possible futures. The freedom is an embodied enablement that can increase or decrease with circumstances, and can evolve with learning.

Many 20th century proponents of the scientific worldview understood that their defining presuppositions entailed a reversible (viz. symmetrically reversing) steady state model of reality (Hoyle et al. 1993). However, contemporary cosmology now accepts the evidence of the Big Bang model as entailing a beginning and a historical emergence through a series of symmetry breaking events (Weinberg 1977). Subsequent symmetries and states of mechanical organization, are unpredictable, logico-mathematically discontinuous and under-determined by the prior order.

Whereas it is unclear whether the spectator representation and the scientific research program can ever make sense of the Big Bang and the series of emergent, spontaneous, and symmetry breaking events, the engineering worldview naturally expects evidence for a qualitatively emergent, conceptually discontinuous history of the cosmos.

Three Examples of the Paradigm Shift to an Engineering Worldview

Against the background of the argument so far, let me provide further examples of this shift from a scientific spectator worldview to an engineering participant worldview. One is from pragmatist philosophy, another is from biology and socioeconomics, and a third is from engineering itself.

1. Royce's Criterion of Self-Referential Coherence

American Pragmatist Josiah Royce argued for Dewey's proposed shift from the spectator to the participant perspective by pointing out that any self-referentially coherent understanding of the universe must be able to make sense of itself (Smith 1969). In other words, the knower and the theory itself must be included in the universe that is to be known. The theory must also be able to account for and make sense of how it was learned. For instance, there would need to be physicists in the physicist's universe that somehow learned the physicist's Theory of Everything. As with Kuhn and others, Royce takes learning to be inherently problematic, requiring real, embodied and novel exploration and experimentation. Since any acceptable theory and its having been learned must be part of the universe, Royce reasons that learning as a process must be an irreducible aspect of any self-referentially coherent understanding of reality. Correspondingly, any meaningfully knowable universe must have a learning process as an irreducible aspect.

The issue Royce addresses is not about self-referential 'consistency' – where consistency might be thought of in logico-mathematical terms. The emphasis on 'coherence' means that any acceptable theory must have the conceptual richness to be able to make sense of the problem of learning and the resulting conceptual developments. Just as there is no way to make sense of quantum choice in the scientific worldview, there is no way to make sense of real questions in any mechanically deterministic universe. Indeed, the quantum choice can be reasonably represented as a question. The contrast that Royce is pointing out is that there is no choice and there are no questions *inside* the mechanical scientific universe. There is no way to make sense of inquiry in a deterministic universe. The scientific spectator representation of inquiry, revealingly, places the inquirer and inquiry itself outside the objective universe.

Suggestive of an overall engineering worldview, Royce argues that since learning is a form of problem solving, any self-referentially coherent understanding of reality must have real problem solving – and embodied participant problem solvers – as irreducible aspects and components of reality.

Accepting Simon's simple definition of problem solving as the attempt to move from a current state of affairs to a more desirable future state of affairs, the engineering worldview naturally sees the universe as attempting to self-develop, evolving through a recursively enabling, cumulative problem solving process. Learning and problem solving are not the abstract spectator's convergence to a final understanding of a fixed reality. In the participant engineering worldview learning and problem solving are embodied in the universe's emergent research, development and deployment enterprise.

Like the pragmatists, engineer Walter Vincenti (1993) argues that engineering provides a more comprehensive epistemological perspective. Engineering is clearly not merely applied science. Rather, what has been represented as scientific knowledge is perhaps merely a tool within the larger context of the engineer's creative problem solving. Petroski (2009; 2012) has further emphasized that, if one wants to better the world, this is the experimental, exploratory, and creative problem solving agenda of engineering: Want to engineer real change? Don't ask a scientist.

2. The Place of Engineering in Biological and Socio-economic Evolution

There is a fundamental conceptual discontinuity in the understanding of the history of life on Earth between the classical scientific worldview, which is identified primarily with the neo-Darwinian approach, and that of the engineering worldview. The move from the neo-Darwinian model to the engineering model requires, per the hypothesis, the same shift from a spectator to a participant perspective.

Critiquing the neo-Darwinian model, Stephen Jay Gould (1989) pointed out that if mutation were random, then if we were to re-run the tape of the history of life, we would have no reason to expect the current outcome, or even anything close to it. Moreover, Gould emphasized that the hypothesized natural selection itself has no overall direction. Adaptation is nothing more than the local natural selection de jour. In effect, the forces of natural selection are just as random, Gould maintains, as the mutations.

When you cannot in principle predict the outcome of a historical sequence, then you cannot explain the actual outcome. The introduction of chance-governed ‘mechanisms’ by the neo-Darwinian theory was apparently the only way to try to make sense of a progressive sequence in a Newtonian-like clockwork model that didn’t naturally allow for any progressive, mechanically discontinuous, qualitative change.

Contemporary neo-Darwinians have abandoned the original inquiry to understand evolution as ‘progressive’ (Carroll 2006). Their current position is that the structure and operation of the modern biosphere is the result of chance. The unexpected consequence is that the neo-Darwinian theory must maintain that the history of life was random. The actual qualitative diversity of life forms is mechanically unexpected; again chance-governed. Similarly, the overall operational structure of the current biosphere, not being clockwork-like, cannot be understood in classical scientific terms and so must be considered random; chance-governed. The neo-Darwinian position is that the history of life on Earth is to be understood as directionless change, with no classically mechanical, causally scientific explanation. It stretches credulity to try to maintain, in light of the fossil evidence, the there is no definable sense in which there is a net progression over the 3.7B year history of life that led to the current biosphere.

When asked for the parameter of progress in evolution, neo-Darwinians deny that there is one, claiming that evolution is merely change (Carroll 2006). This default answer is a consequence of the impossibility of giving any account of qualitative betterment (viz. progress) in terms of a time-invariant order governing reality.

If the evolution of life is a qualitatively emergent engineering enterprise, then the unpredictable revolutionary engineering advances would appear – from the classical scientific perspective – to be non-law governed, in other words, chance-governed. In the engineering perspective the neo-Darwinian chance-governed mutations are understood as creative solutions, as unpredictable inventions, as logically discontinuous engineering advances (Reid 2007).

The shift from a scientific to an engineering worldview can be made by recalling that Darwin modeled ‘natural selection’ on the long history of the engineering strategy of animal breeding: on artificial selection (Darwin 1859). Darwin left open whether artificial selection was to be understood from a sort of spectator perspective as controlled by natural selection. His later writings however would indicate that he took that position (Darwin 1872).

However, consider the opposite problem shift – that all section is artificial. Selection is choice and quantum theory tells us that choice is ubiquitous. Accordingly, the direction in time of any system is determined by participant choice. In the engineering worldview, that choice is understood as embodied in engineering problem solving. Biological evolution in the engineering worldview is a sort of recursive, cumulative, bootstrapping engineering enterprise.

The neo-Darwinian thesis that mutations are the result of errors in reproduction also stretches credulity. If my theory of planetary motion fails to predict positions properly can I just adopt the auxiliary hypothesis that the planets governed by the laws of planetary motion sometimes make mistakes? James A. Shapiro (2011) at University of Chicago has made a strong, evidence-based case that the genetic mutations that arise in biological systems are definitely not random.

Also important in this regard is the work of Robert G.B. Reid. In his monumental *Biological Emergences: Evolution by Natural Experiment* (2007), Reid argues that variations are a deliberate – albeit experimental and exploratory – strategy in life's engineering enterprise. What life is seeking is greater 'adapt-ability', increasing the capacity to do things and to explore new opportunity spaces. The strategy of evolution is not to learn to adapt to a fixed niche but to learn by, and in order to, progressively explore and develop greater capacity to survive and thrive in a wider, emergent range of opportunity-spaces. In support of Reid's line of thinking, recent research shows that life is not merely filling timeless, pre-existing niches. Life is emergent, creating and filing novel, qualitatively novel, non-equilibrium niches (Odling-Smee et al. 2003; Hazen 2012).

In the neo-Darwinian model life was supposed to be seeking a non-progressive adaptive equilibrium. The question of the origin of life's beginning non-equilibrium state of ignorance and uncertainty is never addressed.

3. George Bugliarello's Engineering Biosoma

Neo-Darwinian thinking curiously, but quite naturally, sees modern engineering advances as thwarting natural selection, allowing the less fit to survive and thrive. For instance, the development of insulin therapy has allowed Type 1 diabetics to survive and reproduce (Cooper and Aisberg 2010; Bliss 2007). Advances in cystic fibrosis therapy have extended the average lifespan of victims from 12 years in the 1920s to upwards of 46 years currently (Gawande 2007). By neo-Darwinian thinking these medical advances allow individuals to survive and reproduce who would normally, naturally, perish prior to reproductive maturity. Historian of medicine Thomas McKeown (1962, 1980) argues that nearly all advances in health and longevity in the modern industrialized nations has been due to engineering advances. The preventive measures, such as cleaning up water supplies, have been particularly effective. Those with weaker immune systems who would otherwise have died of cholera, typhus and dysentery – through neo-Darwinian natural selection – lived to survive and reproduce. These engineering advances are counter-evidence to the neo-Darwinian model, in the strong sense of Popper's Question, since the neo-Darwinian conceptual framework has no way to make sense of such progress.

Indeed, the argument for the contributions of engineering to what neo-Darwinians see as counter-evolutionary changes can be taken much further. Early agricultural advances, from irrigation and plowing to domestication of animals, are engineering advances. Refrigeration and food preservation greatly expanded the availability of food. Without these engineering advances natural selection would otherwise have greatly constrained population growth. The control of fire and the development of tools have also aided the survival of the weaker. The modern industrial revolution was based on engineering advances such as the development of the steam engine and the electric motor.

Rather than seeing engineering as unnatural and counter evolutionary, master engineer George Bugliarello (2003) has argued that modern engineering is a coherent extension of biological evolution. In Bugliarello's engineering view, the history of life is better understood as an emergent engineering enterprise. Bugliarello and colleagues also argue that engineering is a social enterprise (Sladovic 1991). In Bugliarello's biosoma (biology-society-machine) theory, biological evolution is the result of a self-enabling, experimentally bootstrapping developmental learning process which results in new more powerful and qualitatively diverse ways to perform work in the world – new ways to do things, problem solve, and bring about a more desirable future.

An alternative history of life on Earth, supportive of the engineering view, also comes from ecological approach to understanding the history of life. Ecologists study the successive historical relationships and the current operational relationships between diverse form of life and between ecological subsystems. The neo-Darwinian perspective, not seeing the expected clockwork biosphere, is unable to make sense of these relationships, consequently seeing them as chance-governed.) Ecologists Dorion Sagan and Eric Schneider (2005) argue that the biosphere is a metabolic engine and that the history of life on Earth is a progressive development of that engine. Certainly there is more life and more types of life in the history of the biosphere. But, there is another factor that ecologists observe in the interrelationships between the various forms of life, in the structure, organizational design and operation of the biosphere as a whole. Sagan and Schneider argue that the biosphere as an engine has become better and better at performing work. Using an engineering imagery, the biosphere engine uses the energy gradient between the Sun (hot source) and outer space (cold sink). The biosphere has emerged in a non-linear manner, over its history evolving an increasing capacity to perform work. In the engineering sense of the concept of work, the biosphere has progressively gained an increasing capacity to do things, become more powerful and developed more qualitatively diverse ways of living. In the engineering sense it has developed, concomitantly, an increasing capacity to explore and experiment. It has developed an increasing capacity to learn new emergent ways of doing things. It has developed an increasing capacity to bring about a more desirable future.

Economist Paul Romer picks up George Bugliarello's theme of the strategic continuity of engineering in biological evolution and modern human socio-economic engineering. David Warsh (2006) tells the story of Paul Romer's paradigm shift in economic thinking. In classical scientific economics, the system always tends toward a non-progressive equilibrium. Any 'apparent' progress was 'explained away' by auxiliary hypotheses, attributed to external, exogenous (non-economic) causal factors. From a classical economic perspective since economic law did not govern these exogenous factors, they were arbitrary and incoherent in terms of those laws, and so considered chance-governed.

By the late 20th century, there was overwhelming evidence of dramatic increases in economic production and productivity over the last 150 years. These increases could not be made sense of in the classical, mechanical zero sum framework. Romer made the revolutionary shift in his famous 1990 paper "Endogenous Technological Change" by arguing that the economy is an engineering enterprise. He maintained that progressive technological development – finding and instantiating new better ways of doing things – was the defining characteristic of all functioning economies. This progressive development is what economic systems have always been doing and are always trying to do (Romer 1994).

Romer argues that a normally functioning economy (viz. metabolic system) is learning and actually generating and expanding its opportunity space. In stark contrast to the neo-Malthusian thinking of the Club of Rome's limits to growth (Meadows 1994), Romer has been characterized as the post-scarcity economist. He argues that ideas (viz. engineering recipes) and new ways of doing things are the key to progressive economic growth and expansion. It is not a matter of how much land, water, iron or gold that you have. It is about what you do with it, about what you do to bring about a more desirable future.

Neither populations nor ecosystems can increase and diversify without increasing opportunities, without *generating* net abundance. Without increasing resources and increasing capacity to perform work, the expansive history of life, noted by Sagan and Schneider, could not have happened. The observed historical expansion in quantity, qualitative diversity, organizational efficiency and operational power of life is precisely what the Malthusian presupposition would not expect and cannot possibly understand. What has evolved is an embodied system that has expanded and continues to seek to expand its capacity to do things, to problem solve, to bring new value into the universe, to bring about a more desirable future.

In his book, *What Technology Wants* (2010), Kevin Kelly explores the engineering worldview making the case that the evolutionary path of progressive technological development is the 'unfolding of freedom' where increasing freedom is increasing ability to perform work and to do things in the world. A better title for Kelly's book might have been, *What Engineering Wants*.

The post-scarcity approach is part of the emerging engineering worldview. Matt Ridley, in his book, *The Rational Optimist* (2010) and Peter Diamantis, in his book, *Abundance* (2012) detail the acceleration of socio-economic-biospheric opportunity of the global engineering enterprise. William McDonough and Michael Braungart's *The Upcycle: Beyond Sustainability – Designing for Abundance* (2013) is another excellent attempt to articulate the overall vision of the abundance framework.

In contrast to the presuppositions of the deterministic scientific worldview, the engineering worldview understands the engineering enterprise (and itself) as creatively developing the future and constructively evolving both the organizational structure and operation of reality. The shift is captured by the problem shift from the spectator to the participant representations of inquiry. For the detached spectator, inquiry seeks to understand how an inquirer-independent (objective) world works. For the embodied participant, inquiry is part of the overall, emergent, bootstrapping engineering research, development and deployment enterprise. The participant is seeking to understand better ways of working in the world and doing things in order to bring about, to instantiate, a more desirable future.

One further step in developing the philosophy of engineering and the engineering worldview would be the cosmology. Engineering cosmology has been competitive with scientific cosmology at least since Plato's *Timaeus* (Jowett 1959) argued that the universe has come to be as it is through the work of the *Architekton*, master architect-engineer) (Zeyl 2000). All 'participants' in the universe are parts or aspects of this universal engineering mind. What I refer to as Sadi Carnot's Epiphany is that we are engineers in a world of engineering (Carnot 2005 Bristol 2015). We are participants in a universal engineering enterprise with abundant opportunity to continually develop the structures and processes of reality to bring forth a better, more desirable future. Carnot's Epiphany derives in part from his insight that all processes are less than 100 percent efficient, less that ideally, classically non-mechanical. This insight is in direct conflict with the calculus of variations and the principle of least action, which are maxims at the heart of the scientific hypothesis. A crucial next move in the articulation of the engineering worldview involves showing that engineering thermodynamics is more general and supersedes the limited, highly idealized attempt to understand thermodynamics mechanically in the tradition of Boltzmann (Bristol forthcoming).

American pragmatist John Dewey's evolutionary philosophy suggests, in keeping with Simon's definition of engineering as seeking a more desirable future, that the aim of the unfolding evolutionary engineering enterprise is 'the construction of the good' (Dewey 1930).

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