The Philosophy of Engineering and the Engineering Worldview

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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 Thomas Kuhn, (1) Sir Karl Popper, (2) Paul Feyerabend (3) and Imre Lakatos (4) – among others.

Engineers Samuel Florman (5) and Walter Vincenti (6) pushed from the other side insisting that engineering was not ‘merely’ applied science and could not be understood within the scientific framework. Henry Petroski has recently argued (7) that all inquiry – even what been thought of as pure scientific inquiry – can only be properly and fully understood within the creative engineering research and development context.

American Pragmatist John Dewey (8) 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 (9) – a complete and consistent correspondence where theory matches objective reality. 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 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 (10) 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, 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. The solution-states – the more desirable futures – are never derivable, predictable or fully determined by the problem/opportunity-states. The Participant Universe – per hypothesis, the Engineering Universe – must have a qualitatively emergent (viz. problem solving) history.

From the Limits of the Philosophy of Science toward the Philosophy of Engineering

There were at least two separate lines of research and reasoning critical of the dominant 20th century Logical Positivist (Spectator) Philosophy of Science (11). One is associated with Thomas Kuhn and the other with Sir 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 (viz. time-space invariant) 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, (12) 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 conceptually discontinuous – revolutionary. The earlier and later theories were incommensurable, meaning that the later theory could not be made sense of – logico-mathematically – in terms of the earlier theory. Feyerabend and Lakatos, in support of Kuhn, argued that if we actually learn – anything – that the later understanding must be qualitatively, conceptually, different from the earlier, pre-learning understanding. Kuhn argued that even with considerable counter-evidence pointing to the inadequacies of an earlier theory, there was no way to 'reason' – logico-mathematically – to the 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 not as logico-mathematically systematic but as 'real' problem solving – genuinely exploratory and experimental. Along the same lines, Feyerabend argued against the Positivist notion that there was one universal (viz. time-space invariant) scientific method. Feyerabend argued that this was equivalent to saying 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 Sir Karl 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 be codified in the literature as 'auxiliary hypotheses'. Frustrated by these endless defensive excuses, Popper reasoned that any legitimate (viz. truly scientific, self-critical) research program should be able to articulate prior to an experiment or, indeed, prior to all possible experiments, what evidence, if it were to occur, would lead the proponents to abandon the core hypothesis defining their research program. The extension of the argument that all meaningful theories must be falsifiable is, what I have come to call, Popper's Question: what evidence, if it were to occur, would lead you to abandon the core defining hypothesis of your research program. (13)

The first unexpected development was the recognition that legitimate scientists also quite commonly use these 'after-a-failure' defenses of 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. Oops! There isn't anything there. Undaunted, the scientist offers another auxiliary hypothesis that there is a dust cloud blocking the telescopic view. He 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, first, that scientists use auxiliary hypotheses quite regularly; second, 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 hypothesis. The third lesson is that it is unclear just how long this 'rationalizing defense' of a core hypothesis can reasonably continue. (For a real, ongoing case study, see my treatment of 'Dark Matter'. (14))

Given that regular 'legitimate' scientific inquiry uses auxiliary hypotheses in defense of core 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 of an otherwise developing research program. Pressing the operational case, the 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 is only possible if in fact the core hypothesis is actually false in this universe. The consequential conclusion is that all meaningful, falsifiable theories must actually be false. What is meant by 'false' here is simply 'incomplete' (viz. conceptually incomplete). Even highly successful theories incorporate idealizations and so are technically false, not universally true; incomplete. Unexpectedly, the incompleteness turns out to be demonstrated by evidence (viz. a phenomenon) that, by its very nature, cannot be made sense of – conceptually – 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 – in terms of the conceptual apparatus of the core hypothesis in question. What Popper's Question is asking for is some evidence that cannot possibly be made sense of, let alone explained, in terms of the research program defined by the core hypothesis – come what may.

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 phenomenon can then presumably be understood as confirming an equally meaningful, falsifiable – per hypothesis, complementary – theory.

Both the Kuhnian and Popperian lines of research and argument serve to establish the inadequacy of the Spectator representation of inquiry and learning. The arguments and historical evidence for the limit of this classical, Logical Positivist Philosophy of Science calls for a more general, superseding representation of inquiry. One meta-lesson is that one can experience the limits of a theoretical system while remaining in that system. The experience of limits is often confusing and paradoxical. As Kuhn emphasized from his historical studies a theory plus counter-evidence to that theory does not logically lead to the more general superseding theory. The advance from one theory to a superseding more advanced theory is logico-mathematically non-linear. The later theory is conceptually discontinuous with the earlier.

As a student working with Popper, Feyerabend and Lakatos it gradually dawned on me that they weren't arguing *from* a theoretical position, but rather 'backing into' (viz. toward) an emerging new theoretical position through their increasingly penetrating and sophisticated critique of the Positivist position. The apparent meta-lesson is that new superseding paradigms become apparent only through a gradual critical process – cumulative afterthought – revealing the limits of the earlier paradigm.

The critique of the Positivist representation of inquiry calls for a More General Theory within which all meaningful falsifiable theories are 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 the More General Theory. Kuhn establishes that learning is non-linear involving conceptual revolutions – logico-mathematical discontinuities. Our conceptual understanding of reality develops – qualitatively. Kuhn argues that since learning is not systematically logico-mathematical, learning is problematic. Advances are solutions that cannot be deduced from the prior understanding. Indeed, even a theory plus clear counter-evidence doesn't logico-mathematically lead to a more advanced superseding understanding – to a solution.

One 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. Learning is conceptually emergent.

There are several important clues to the nature of the More General Theory associated with Popper. 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 mechanical theory. As Lakatos pointed out, the very process of formulating a scientific (mechanical) 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 – since it is bias and incomplete – 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.

From the Limits of the Scientific Worldview toward the 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 (15) forced the embrace of complementarity. (16,

17) ‘Particle’ in the Newtonian framework is conceptually discontinuous with ‘wave’ of the Maxwellian framework. This generated the search for a More General, superseding, post-scientific, post-objectivist understanding of reality. Complementarity entails that the participant-inquirer is encountering a universe that is not governed by One universal, objective order that uniquely determines 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 Schrodinger wave-function. This is the collapse of the possibility space, brought about by the observer’s active choice to implement one type of experimental setup rather than others possible. That choice is, by its very nature, ‘scientifically arbitrary’ – having no objective mechanical determinant or post-facto explanation.

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 Scientific Hypothesis. The choice is conceptually discontinuous with all possible models of classical deterministic physics. The choice between complementary opportunities is a qualitative choice. If choice is a real phenomenon, it is scientifically incoherent – a phenomenon outside what can be made sense of or explained within the Scientific Research Program – come what may. 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.

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

The Paradigm Shift can be represented as a Problem Shift. In the Scientific Framework the detached, Spectator’s problem of inquiry was to understand ‘how the world works’ –

objectively, independent of the inquirer – with no anticipation of practical benefit. 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' or 'incoherent', the Engineering Worldview understands the choice 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.

The many 20th century proponents of the Scientific Worldview saw that their defining presuppositions entailed a reversible (viz. symmetrically reversing) Steady State Model of Reality. (18) However, modern cosmology now accepts the evidence of the Big Bang Model entailing a beginning and an historical emergence through a series of mechanical symmetry-breaking events. (19) Subsequent symmetries, states of mechanical organization, are unpredictable, logico-mathematically discontinuous, by their very nature – under-determined by the prior symmetries.

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' symmetry-breaking events, the Engineering Worldview naturally expects evidence for a qualitatively emergent (viz. conceptually discontinuous) history of the cosmos.

Examples of the Paradigm Shift to the Engineering Worldview

1. Royce's Criterion of Self-Referential Coherence

It is not just choice that is conceptually incoherent within the Scientific Worldview. Curiously, there are no questions in its mechanical universe and no way to make sense of inquiry. The Spectator, and tacitly the Logical Positivist representation of inquiry – revealingly, places the inquirer outside the 'objective' universe.

American Pragmatist Josiah Royce argued for Dewey's Paradigm Shift from the Spectator to the Participant. (20) Royce pointed out that any self-referentially coherent understanding of the universe must be able to make sense of itself. In other words, the theory itself must be included in the universe that is to be understood. It must 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 et al., Royce takes learning to be inherently problematic, requiring real, embodied, 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 understandable 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 the theory must have the conceptual richness to be able to make sense of the problem of learning. Just as there is no way to make sense of choice in the Scientific Worldview, there is no way to make sense of 'real' (viz. really problematic) questions in any mechanically deterministic 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 convergence to a fixed reality. In the Participant Engineering Worldview learning and problem solving are embodied in the emergent research, development and deployment enterprise.

Along the same line of reasoning Royce's colleague Pragmatist John Dewey characterizes reality's engineering enterprise, seeking more desirable futures, as 'the construction of the good'. (8) The American Pragmatism of Charles Sanders Peirce, William James, Josiah Royce and John Dewey (21) appears to be an early articulation of the Philosophy of Engineering and the Engineering Worldview.

Walter Vincenti brilliantly argues that engineering is the more comprehensive epistemological perspective. (22) Engineering is clearly not 'merely' applied science – not a logico-mathematical extension of scientific (mechanical) knowledge. Rather, what has been represented as 'science knowledge' is perhaps 'merely' a tool within the larger context of the engineer's creative problem solving. Henry Petroski recently emphasized the point that if one wants to better the world this is the experimental exploratory, creative problem solving agenda of engineering: – 'Want to Engineer Real Change? Don't Ask a Scientist'. (23, 24)

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 – identified primarily with the neo-Darwinian approach – and the Engineering Worldview. The move from the neo-Darwinian model to the Engineering model requires, per hypothesis, the same Paradigm Shift from a Spectator to a Participant perspective.

Critiquing the neo-Darwinian model Stephen Jay Gould pointed out that if mutation is 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 mechanical model that didn't naturally allow for any 'progressive' (viz. mechanically discontinuous, qualitative) change.

The current neo-Darwinians have abandoned the original inquiry to understand evolution as 'progressive'. (26) 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 'merely' 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 leading to the current biosphere.

When asked for 'the parameter of progress' in evolution, the neo-Darwinians deny that there is one, claiming that 'evolution' is 'merely change'. (26) 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. The neo-Darwinian 'mutations' are, on reflection, seen to be, novel, logico-mathematically (mechanically) discontinuous engineering advances. (27)

The Paradigm Shift to the 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. (28) Darwin left open whether artificial selection was to be understood (viz. from a sort of Spectator perspective) as controlled by natural selection. His later writings however would indicate that he took that position. (29)

Consider the opposite problem shift – that all section is artificial. Selection is choice. 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, at University of Chicago, has made a strong, evidence-based case that the genetic mutations that arise in biological systems are definitely not random. (30) Perhaps most important is the work of Robert G.B. Reid. In his monumental, paradigm shifting study: *Biological Emergences: Evolution by Natural Experiment*, (27) 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 capacity to do things, 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. (31, 32) In the neo-Darwinian model life seeks a non-progressive adaptive equilibrium.

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. (33, 34) Advances in cystic fibrosis therapy have extended the average lifespan of victims from 12 years in the 1920s to upwards of 46 years currently. (35) 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 argues that nearly all advances in health and longevity in the modern industrialized nations has been due to engineering advances. (36, 37) 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 – counter-evidence 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 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 anti-natural and counter-evolutionary George Bugliarello taught his students that modern engineering is a coherent extension of biological evolution. (38) 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. (39) In Bugliarello's biosoma theory (38) biological evolution is the result of a self-enabling, experimentally bootstrapping developmental learning process resulting in new more powerful and qualitatively diverse ways to perform work in the world – new ways of doing things, new ways to problem solve and bring about a more desirable future.

An alternative history of life on Earth, supportive of the engineering view, comes from ecological approach to understanding the history of life. (Note: Interestingly ecologists study the historical-succession relations 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 relationship, consequently seeing them as chance-governed.) Ecologists Dorion Sagan and Eric Schneider argue that the biosphere is a metabolic engine and that the history of life on Earth is a progressive development of that engine. (40) 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 relationships 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, more powerful and qualitatively more diverse things. In the engineering sense it has developed 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 tells the story of Paul Romer's paradigm shift in economic thinking. (41) In classical scientific economics the system always tended 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 20^{th} century, there was overwhelming evidence of dramatic increases in economic production and productivity over the last 150 years. These could not be made sense of in the classical framework. Romer made the revolutionary Paradigm Shift in his famous 1990 paper "Endogenous Technological Change". (42) Romer argued that the economy is an engineering enterprise. He argued 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. (43)

Romer argues that a normally functioning economy (viz. metabolic system) is learning and actually generating and expanding its opportunity space. In contrast to the neo-Malthusian thinking of the Club of Rome (Limits to Growth), (44) Romer has been characterized as the post-scarcity economist. He argues that ideas (viz. engineering recipes) – new ways of doing things – are the key to progressive economic growth and expansion. It is not a matter 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 – increasing capacity to perform work – the expansive history of life, noted by Sagan and Schneider, could not have happened. The 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 make sense of. 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*, Kevin Kelly (45) 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, 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*, and Peter Diamantis, in his book, *Abundance*, detail the acceleration of socio-economic-biospheric opportunity of the global engineering enterprise. William McDonough's recent book, *The Upcycle: Beyond Sustainability – Designing for Abundance*, is an excellent attempt to articulate the overall vision of the Abundance Framework. (48)

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 Paradigm 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, better ways of doing things in order to bring about, to instantiate, a more desirable future.

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 evolutionary engineering enterprise is 'the construction of the good.' (8)

Addendum: Carnot's Epiphany: Cosmology from an Engineering Perspective

There is one further step in developing the Philosophy of Engineering and the Engineering Worldview. Engineering Cosmology has been competitive with Scientific Cosmology at least since Plato's *Timaeus* (49) argued that the universe has come to be as it is through the work of the Architekton (Master Architect-Engineer). (50) All 'participants' in the universe are parts or aspects of this universal Mind. What I refer to as 'Sadi Carnot's Epiphany' is that we are engineers in a world of engineering, 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 – classically non-mechanical. This insight is in direct conflict with the calculus of variations and the principle of least action – 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. (52)

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