2009-01-01

An Evolutionary Perspective on Engineering Design

William Grimson
Technological University Dublin, william.grimson@tudublin.ie

Mike Murphy
Technological University Dublin, mike.murphy@tudublin.ie

Recommended Citation

Grimson, W., Murphy, M.: An Evolutionary Perspective on Engineering Design. Engineering in Context (Christensen, S., Delahousse, B., Meganck, M. eds) pp.263-276. Aarhus, Academica, 2009. ISBN:978-87-7675-700-7

Chapter 13

An Evolutionary Perspective on Engineering Design

William Grimson & Mike Murphy

Abstract: Natural Selection has provided a powerful explanation of how life evolved and evolution has been used as metaphor and model to provide insight into how technology and artifacts have developed. While recognising that Darwinian evolution does not proceed on the basis of a target or particular design outcome, the activity of engineering does proceed within what might be called an intelligent design framework. Evolution provides interesting parallels as to how engineering design has developed and is carried out. In particular the identification of useful traits, in a post hoc and natural selection-like manner, is a powerful mechanism that drives improvement. Further, serendipity plays a role in engineering as it does in biological systems. The mechanisms might be different but the characteristics of how "chance" influences outcome share many features. The mimicking of biological systems in engineering design is currently a vibrant research activity. In another parallel with evolution, Darwinian principles can be used to explain how ideas are propagated. This chapter summarises the main concepts of Darwinian evolution and finds examples in engineering where evolution-like behaviour can be observed, and where such material could be included to good effect in the engineering curriculum.

Key words: Evolution, Adaptation, Vestigial, Meme, Design, Technology

Introduction

Charles Robert Darwin was born 200 years ago on the 12th February, 1809, and it is now 150 years since his book *The Origin of Species by Means of Natural Selection* was first published. In Darwin's words

"As many more individuals of each species are born than can possibly survive, and as, consequently, there is a frequently recurring struggle for existence, it follows that any being, if it vary however slightly in any manner profitable to itself, under the complex and

sometimes varying conditions of life, will have a better chance of surviving, and thus be naturally selected. From the strong principle of inheritance, any selected variety will tend to propagate its new and modified form".

By any measure Darwin's book and the central idea it contains ranks amongst the most important ever published and its impact has transcended its biological domain. The words evolution and evolutionary, used in both everyday language and more specialist fora, often carry meanings sometimes hidden but which nevertheless are connected to the ideas formulated by Darwin. Engineering and technology are not excluded. It is observed that engineering techniques and "know-how" come about by a process of inheritance, proceeding in a sequence of often small steps that involves a process of selection. Likewise for the physical products and artifacts designed by the engineer, and for which it appears impossible to avoid using that powerful word *evolution*. Engineers naturally use expressions such as "the design of the combustion engine evolved slowly at first", "the evolution of software design paradigms was influenced by practitioners favouring those that met their needs", "early designs of transistor amplifier circuits evolved from their pre-cursor vacuum tube counterparts". Although in each case what exactly evolved, what mechanisms were involved, and under what circumstances might or might not be clear, but undeniably there exists the sense that a number of evolutionary concepts such as inheritance, incremental change and adaptability apply. We will see later in this chapter that a number of writers have described evolutionary theories of technology where concepts and associations are both inspired by, and are linked to, biological evolution.

To anchor some initial thoughts by way of a tangible and visual example, consider two bridges: the first is a rope suspension bridge spanning a deep canyon in South America and the second is a modern steel and concrete suspension bridge. The catenary geometries of the main cables are similar, both have decks to carry traffic (whether it be people, cars or trains). Both use vertical suspension ties supporting the deck that are joined to the main suspension cable and which are identical in function and similar in form. It is natural to consider whether primitive but effective rope bridges contributed to the development of modern suspension bridges (Ochsendorf, 2005). Specifically, how were design ideas communicated amongst bridge builders, what techniques were shared, what were the circumstances under which new ideas or techniques were brought to bear, how did developments in other technologies influence the progression of bridge design, what selection processes were involved, etc.? These and other questions would provide insight as to the validity of any theory of evolution of technology. Other design "spaces" could be considered, such as bicycles, aircraft, cars and even the humble paperclip (Petroski, 1996). The contention is, very simply, that by examining the history of technology and engineering it is almost inevitable that an evolutionary perspective emerges.

The aim of this chapter is to examine the parallels and similarities of how things evolve in the biological sense and the artificial sense (resulting from engineering design) with the intention of gaining another perspective of the process by which engineering outcomes are achieved. The hypothesis that is being explored is whether it would be beneficial to educate engineers in evolutionary theory not just as part of a liberal education but as an instrument to making them more aware of the general milieu in which they work.

Revolution or Evolution?

Elements making up the evidence to support evolution as a process of development in the general sense pre-date Darwin. As Isaac Newton wrote to Robert Hooke in 1676, "What Descartes did was a good step. You have added much several ways, and especially in taking the colours of thin plates into philosophical consideration. If I have seen a little further it is by standing on the shoulders of Giants". Newton uses the metaphor of seeing a little further on the shoulders of others to illustrate that progress is based on inherited knowledge and does not necessarily proceed by mighty leaps, rather it advances in small increments, i.e., *a little further*. Also, by looking back in time, Newton acknowledges that the action of selection is involved in the process of scientists recognizing the value or fitness of the work of their predecessors.

According to Kuhn, "successive transition from one paradigm to another via revolution is the usual developmental pattern of mature science", but over time this view was modified to accommodate what might be called a gradualist model (Kuhn, 1962). Retrospectively and at some distance, many revolutions seem less revolutionary and more evolutionary in character. If this is true for science then perhaps it is also valid for the artificial, the artifacts created by, amongst others, engineers. In a minor way, the debate within the realm of science that followed Kuhn's book was mirrored in the biological world when it was argued by Stephen Gould that evolutionary change in the fossil record came in fits and starts rather than in a steady process of slow change, what was termed punctuated equilibrium (Gould, 2007), which stands against orthodox evolutionary views (Dennett, 1996).

Whatever stance one takes on revolution versus evolution, borrowing ideas from one domain and examining them in a different context may lead to an enriched understanding either through a rejection of the applicability of the "carried over" concepts or through a validation of at least some of the concepts.

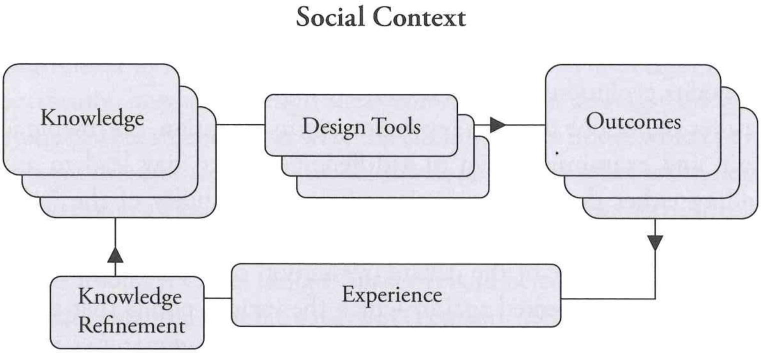
To support either side of the debate (revolution or evolution) a model of engineering design is first presented against which the various points that emerge can be referenced. Second, some criteria are stated that facilitate judgment as to what extent a theory is considered to be "weakly" or "strongly" evolutionary. In addition we consider a set of "projections" by which the validity of the claim can be tested that evolutionary theory can contribute to understanding how engineering design takes place. The projections chosen for reflection are Selection, Vestigiality, Memes, Adaptation, and Biomimetics where in each case there is supportable evidence for the conceptual links between the biological and artificial world.

Dawkins characterises a complex object as one that is statistically improbable in a direction that is specified not with hindsight (Dawkins, 1996, p.24) and many technological artifacts display a degree of complexity that almost defy comprehension (certainly for the average man or woman). The temptation can not be resisted to reverse William Paley's famous watch argument and suggest that nature, like technically complex artifacts, could only have resulted from a process of incremental development! A major difference being the time scales involved and which are so different.

A Model of Engineering Design

To provide a framework for the ideas in this chapter a basic model of engineering design is depicted in Figure 13.1 (Christensen *et al.*, 2007, p.144). To begin at the end: a new generation of knowledge (knowledge refinement) results from the wisdom gained by the experience of evaluating the outcomes of the current generation of knowledge. Typically what existed at the start of the design process was a new generation of knowledge but which is now augmented as a result of having completed the design and having carried out an evaluation of its fitness for purpose. The new knowledge might be in mathematics, science, technology, methods (including know-how), as well as a richer insight into the context in which the design is taking place.

Figure 13.1: A Basic Model of Engineering Design



If we loosely equate evolution with change we note that change is typically manifested everywhere in the design cycle. Requirements shift and change; methods to gather, assess and specify requirements change; the knowledge on which a design is based changes; the methods used to carry out a design change; the methods used to evaluate outcomes change; the context in which outcomes are evaluated by end-users change; the tools used in refining knowledge (including the methods used) change; and the outcomes can cause the requirements to change. At each point in the design process selections are made. Given the engineering goal of a target or particular design outcome, the safest way all such potential change can be managed is by adopting an "evolution and not revolution" approach, and consequently much of engineering is based on that cautious conservative dictum.

The next section presents three evolutionary theories of technology that are referenced back to the model presented above and provides criteria by which they can be judged as being weakly or strongly evolutionary.

Evolutionary Theories of Technology

"Could it be that technology, too, is really the outcome of evolutionary processes rather than intelligent design?" asks Philip Brey writing in the book *Philosophy and Design*. Brey questions whether the origins of biological organisms and artifacts are radically different (Vermaas, 2008, p.61). To examine this, the most direct approach is to set out reference points or criteria by which the analogy between the natural and man-made world can be discussed. Brey suggests three but this is adapted here to four criteria as follows:

Genotype: coded information in genes by which cells and organisms can be replicated
Phenotype: observable characteristic of an organism that results from an expression of a gene
Inheritance: variation that is expressed and capable of being passed on to a succeeding generation
Fitness: process by which the differential fitness of a member of a species to adapt to an environment can be identified.

In the case of a technology that has resulted from processes that can be compared to all four of the above criteria, then there is evidence to support a strong evolutionary theory of technology. Alternatively, if there is only a match with one or two of the above criteria, then only a weak evolutionary theory can be supported.

Brey summarises three evolutionary theories of technology due to Basalla, Mokyr and Aunger and which are briefly re-stated here (Aunger, 2002; Basalla, 1988; Moykr, 1996). Basalla's key point is that it is artifacts that are central to a theory of evolution of technology. Artifacts are the analogue of phenotypes and selective pressures operate to promote one artifact over another. The selective pressures could arise from a range of factors that we experience such as economic, social, climatic or cultural. Mokyr's theory on the other hand takes technical knowledge as the unit of analysis, which includes scientific and engineering know-how or craft. Mokyr's view is that mathematics and science are essentially analogous to the genotype and that it is craft and know-how that allows an artifact to be created or expressed and therefore is analogous to the phenotype. Aunger centres his theory on memetics and therefore attributes technical change to how ideas are communicated within and outside of a social grouping over time.

"*According to memetic theory, human culture is realized and transmitted through cultural units called memes, which are units of meaning that can express any culturally determined idea, behavior, or design. Memes are like genes in that they can replicate and can be transmitted, and they compete with other memes for survival according to Darwinian principles*" (Vermaas, 2008, p. 63).

These three evolutionary theories are really three viewpoints of the same thing: they are complementary regarding the artifact, the know-how and the meme and together lead to a more complete understanding of how technology evolves. It is important to note, first, that it is only a human that could distinguish between the artifact, the know-how and the memes. For example, a skilled craftsperson picking up a piece of work by an individual will not only know how it was made but often, with high probability, who made it and hence the ideas that were behind its production. All three of these aspects co-exist; there is a unity between the artifact, the know-how, and the memes. Second, each theory has weaknesses. Basalla's doesn't deal adequately with mutation; Mokyr's finds no room for serendipity and is weak with respect to innovation; and Aunger's fails to adequately explain the links between memes and artifacts.

Consequently there is the prospect that the above theories can be unified into a single theory. Referring back to Figure 13.1, the outcomes can be considered to be essentially the artifacts of Basalla, the design tools can be the know-how of Mokyr, and knowledge the memes of Aunger. That leaves the experience and knowledge-refinement to be positioned within the unified theory. Taking the three theories together, the missing dimension is how experience and knowledge refinement (a combination of evaluation and selection) is to be included in such a unified theory. The ideas of Langrish, who introduced three types of memes, add to the ideas of Aunger and provide the moderation mechanism by which the stages of the design model in Figure 13.1 become connected as will be discussed later in the chapter (Langrish, 1999). To conclude – the three theories introduced above are compatible with the basic model of engineering design presented and this constitutes therefore to some extent a dual form of validation. Also, it should be emphasised that the social context background, in which any design process is situated, highly moderates the overall operation through a complex flux of memes.

Natural Selection and Selection in Engineering

Natural selection is the process by which heritable traits, which are favourable in the sense of enhancing survival, become more common in successive generations, as described by Darwin. The word "natural" serves to distinguish the blind selection of nature from the selection controlled by man and which might be termed artificial on which Darwin commented "how great is the power of man in accumulating by his selection successive slight variations" (Darwin, 1859). The word "artificial" here comes with a warning as its use might by some be restricted to man-made non-biological artifacts consistent with the dictionary definition "an object made or modified by human workmanship, as opposed to one formed by natural processes" (Oxford English Dictionary). There is a need for care in the meaning and use of "artificial" as the actions and capabilities of man close in on those of nature. Consider selective breeding, a term used to denote an artificial selection wherein its employment is mainly associated with the domestication of animals (cattle, horses, cats, dogs) and plants (wheat, vines, rice). In these cases the process of reproduction is natural but the selection is controlled by man and with a purpose in mind. Going further, with genetic engineering artificial selection is possible and this involves having an impact on the reproductive processes themselves.

Artificial selection is a characteristic of engineering and in particular engineering design. The identification of traits and subsequently their retention in succeeding generations of devices and products are commonplace in engineering even when the underlying cause or explanation of why a trait exists is not always fully understood. In fact it might not be going too far to state that progress in engineering would have been slower if such selection had not been allowed. There is one very significant difference between natural and artificial selection: natural selection has no target and it has no mechanism by which a target design could be considered; whereas artificial selection, through the involvement of a human designer, has the capability of envisioning an outcome in which a particular trait is retained or indeed enhanced. After the event of having completed an engineering design, "selection" will either recognise the advantage of the required trait and allow it to be retained or the trait will be missing and the design rejected. Here "selection" is the act of observing and choosing. Serendipity is a special case of artificial selection where an unplanned or untargeted result is recognised and which in turn forms the basis of future products. Examples include the X-ray machine, thermionic valves, and the world-wide-web.

And what of the failure of particular designs? In nature, survival of the fittest is the default mechanism which allows poor "designs" to be eliminated or marginalised. Whilst nature does not design in the sense that an engineer does, the retrospective judgment, albeit by different means, is similar between nature and engineering. But there is an important difference and Petroski has written about the role of failure in engineering and how important it is in accumulating knowledge about specific design environments (Petroski, 1985). Nature does not appear to have the same ability, rather its investment is in what survives. Engineering, on the other hand, has a collective memory contained in a set of memes which can be inherited and modified in the light of further experience. Nevertheless it is worth considering failure in engineering as an evolutionary process and to examine over a period of time the main trunk of progress and the branches that led nowhere.

Vestigiality

Vestigiality, in the biological sense, refers to the situation in which organs or organisms have lost all of their original function in a species, but nevertheless have been retained through evolution (they have not been de-selected). The issue is not without dispute but it is commonly held that the appendix and the coccyx in the human are vestigial. The wings of flightless birds are vestigial. It can be imagined that deselecting such vestigial elements carries no great advantage and could only be warranted if survival was an issue. The question for this section is whether vestigiality is in evidence in engineering or in general man-made objects. Some examples follow to show this to be the case.

The computer system on which this text is being typed uses a QWERTY keyboard. In old mechanical typewriters it was not uncommon, if the typist was too fast, for the thin metal arms carrying the typeface to clash and jam, and consequently fail to hit the inked ribbon by which a letter could be printed on a line of a page. To slow down the process, and hence make such jamming more infrequent, the distribution of the letters on the typewriter were deliberately arranged to minimize this jamming; hence the odd and inefficient design of our modern keyboard. Deselecting the QWERTY layout of the keyboard appeared to be too costly and so it remains in use even though the original reason for it (function) is no longer valid. Alternative keyboards do exist but they are not in common use.

Another example of vestigiality are serif fonts. A serif font is one that exhibits little hooks or strokes at the beginning or end of a letter (for example the little bar at the end of the letter q, and the little stroke at the top of the letter b). The origin is not uncontested but one explanation is that the stone masons of antiquity had to work down into the stone with their chisels before the main body of the material forming the letter could be removed. This leading-into and out-of the stone with the chisel caused tell-tale little hooks and strokes. With modern print technology this original reason is no longer necessary, but we associate the serif font with something desirable by virtue of its classical origins. Here function has transformed into form.

Marooning is a word occasionally used to describe something that is very close to being vestigial but where there is a new reason for retention, usually of a form replacing a function. An example is the use of lampshades which originally were a safety device and a means of protecting naked light from drafts. The need for this protective function of lampshades is no longer necessary; however they are retained for ornamental and possibly conservative reasons (i.e. not wanting to do away with the old).

But why would engineering retain a redundant element? Consider a car engine block which is expensive to design and produce and needs to have a certain life-span to justify the cost involved. The block is complex and will have apertures, lugs, chambers, etc. which all serve to house other components that collectively form the engine. Over the life-span of the block new components become available which might replace original ones and possibly make other components redundant. In the latter case the original block, if possible, would be retained and the particular function associated with the redundant component would be retained. The cost of de-selecting by producing a new block might be prohibitive. To exaggerate, perhaps, the very survival of the model would outweigh the need to tidy up the block design.

Consider next a computer program having many thousands of lines of code. The program might be critical with respect to some operation and will have been tested as thoroughly as possible. Suppose, because of changing circumstances in the overall program operation, that some part of the functionality of the program is no longer required. The question will arise as to whether the code should be modified. A conservative approach would leave the now-redundant code in the program as any change made would result in the necessity to carry out an extensive and possibly expensive set of software tests.

As a final example, consider a dual-decked bridge designed to carry trains on one level and cars on the other. In the event that changes in the rail network mean that rail traffic is no longer routed over the bridge, then the original function of that deck is removed. Thus changes made to one part of a greater system (bridge and rail network) have made one feature of the bridge redundant. It may be prohibitive to re-engineer the train deck and a decision might be made to simply preserve the deck but not to use it.

As in nature the ability to have vestigiality is an essential prerequisite for having the ability to change. It is one level of difficulty to select on the basis of a single trait but it is more difficult and rare to select on two different traits at the same time (within the same generation). So it is not too surprising if in natural selection a single aspect that improves survival is chosen and something that is essentially survival-neutral is simply left alone: it is clear where the advantage lies. In engineering the same feature is observed. The earliest motor powered vehicles looked very much like horse-drawn carriages simply because that is what they were. The designer had a difficult enough task in proving that a mechanical means of providing "horsepower" would work without trying to optimise the whole system simultaneously. The improvement in wheels, advances in suspension, weather-proofing, enhanced aerodynamics would all wait for successive generations of design. Trying to do all at once could result in multiple failures. If in the process something becomes redundant or marooned then that vestigial aspect can be accommodated, at least for a period of time, as to do otherwise might jeopardize the whole system.

From Blueprint to Product

A parallel can be drawn between the role of RNA in producing proteins, having copied the essential information from DNA, and the engineering fabrication of a product from an engineering blueprint. DNA itself is not used directly in making these proteins. In engineering the blueprint might be a set of drawings or a physical master copy, both of which are readable and neither of which are used directly in mass production of whatever manufactured good is envisaged. In the case of RNA there are a number of regulatory mechanisms in place. Likewise in engineering, steps are taken to ensure that what is produced is a "fair" copy of what was intended. But small errors of transcription and production do occur and these will subsequently be found to be either of no consequence or seen as significant (desirable or otherwise) which can lead to product improvement or production improvement (additional regulation or control). Much of what happens within the world of DNA and RNA has characteristics that would be recognisable to a student of computer databases. It could also be said that reading, writing, deleting, editing, copying, modifying are all words that provide a link between the biological and computer engineering worlds.

Memes

Evolutionary principles can be extended to explain how ideas are distributed or spread. Richard Dawkins introduced the word *meme* in his book *The Selfish Gene* replacing the word gene with meme (Dawkins, 1989). Langrish added to the idea by proposing three types of meme: recipemes, selectemes and explanemes. They were then used within an evolutionary framework to discuss technological innovation (Langrish, 1999). As mentioned earlier it is attractive to import the concept of these three types of meme into the theory of Aunger.

"Recipemes" are a set of ideas for how to do things. And implicit in this is that the ideas are in competition, with the successful recipemes being the ones favoured for replication, perhaps with some small modifications over a period of time. Knowing how to do something might be considered a skill and might also be thought of in terms of a craft.

Langrish uses the word "selecteme" to mean ideas that form the basis of selection of a method or product. Selection must take place within a context in which criteria are chosen and decisions taken with respect to what is best or perhaps just better than an alternative. Langrish uses the word "betterness" to describe what this action is centred on. The communication or transmission of selectemes happens mainly between members of whatever group is directly concerned with making specific selection decisions.

The third type of memes Langrish called "explanemes" which are ideas that are used in helping to understand how things work or work better than alternatives. Again competition is a feature of explanemes – this is particularly the case where the subject matter is not strictly rational. Explanemes are communicated with the aid of a range of languages where mathematics might be considered to be a particular type of language. Engineering generally communicates its explanemes in a wide variety of ways: plain text, drawings, mathematics, models etc. Engineering journals of research and development abound in competing explanemes!

Referring back to Figure 13.1 it is easy to place recipemes, selectemes and explanemes within the model. Selectemes are involved in deciding what knowledge is appropriate in a specific case, recipemes are fundamental to carrying out a design using whatever tools have been chosen. The anticipated outcomes are a function of the explanemes used in designing and selectemes are used to determine the "betterness" of the product. Knowledge refinement is an evolutionary process by which the three types of memes are modified over time and in the light of experience and accumulated wisdom. Engineering schools and professional bodies amongst others play important roles in codifying, maintaining and communicating these memes within a community or society. And occasionally these memes are transferred to influence other groups and then take on a new life or evolutionary path as a mutation or as a crossing over to another species.

Adaptation

Adaptation in nature is largely about preferring changes that have in some way made it possible for a species to exist more easily, or survive in its environment. In nature adaptation is conferred after the event since there is no way of knowing in advance that survival is to be enhanced, whereas in technology the changes are made knowing that an improvement is being designed to generate a specific result. Adaptation occurs in many forms in engineering and just a few examples will be given here.

The Theory of Inventive Problem Solving (designated TRIZ) was developed by Altshuller and consists essentially of a methodology with a tool set by which innovative ideas can be explored and problems solved. The tool set includes the laws of evolution together with such expected elements as "standard solutions". Since its original development in 1946, it has been demonstrated that problems and solutions were repeated across industries and sciences, patterns of technical evolution were repeated across industries and sciences and that innovations used scientific effects outside the field where they were developed (TRIZ). According to Madara Ogot "the power of TRIZ ... is its inherent ability to bring solutions from diverse and seemingly unrelated fields to bear on a particular design problem, yielding breakthrough solutions" (Ogot, 2004, p.194).

It is clear that the meme concept sits well with TRIZ as recipemes, selectemes and explanemes all have their place in logically sorting through the many possible ideas that eventually contribute to a good design. Ogot's model extends the black-box model used in TRIZ by explicitly including "harmful and insufficient energy, material and signal flows within the system." The end result is that, in part at least, a design process results that can improve a system with little or no change: in other words an adaptive process.

As a second example, adaptive digital filters can be designed that allow some changes to be made to the filter's parameters that result in a "better fit" with the environment in which it operates, such as in noise cancelling systems. But it is an outside agent and not the filter itself that judges whether the adaptation is good or otherwise, by setting criteria by which the adaptation is driven.

Biomimetics

Engineering is increasingly looking to living systems to help create new products or enhance existing designs. Biomimetics is the study of the structure and function of living things which are then used as models to inspire the creation of new materials or products. In part this study involves reverse engineering by which a function is inferred from a structure (Richardson, 2002). Whilst biological "designs" do not attempt to be optimum (there being no mechanism for biological systems to know, record or make use of the concept of optimality) they are over the course of time very good at exploiting environmental niches (Vincent *et al.,* 2006). It is this exploitation that is at the core of biomimetics' borrowing from nature.

> *"Engineers ... are pondering the bumps on the leading edges of humpback whale flukes to learn how to make airplane wings for more agile flight. ... the fingerlike primary feathers of raptors are inspiring engineers to develop wings that change shape aloft to reduce drag and increase fuel efficiency. Architects ... are studying how termites regulate temperature, humidity, and airflow in their mounds in order to build more comfortable buildings"* (Mueller, 2008).

Of course the manner in which an engineer exploits nature is almost impossible to imagine being paralleled biologically. Other examples of borrowing from nature include the invention of hook-and-loop fasteners (e.g., Velcro^{TM}) which was inspired by the burrs on a dog's coat; reducing drag on a water-borne vehicle by mimicking the structure of a shark's skin; anti-reflective coatings that owe their existence to the study of the eye of a moth; and human flight was certainly inspired by birds with early attempts as human flight centred on copying the wing structure of idealized birds.

A number of universities have research centres for biomimetic engineering, and the topic is beginning to appear in some undergraduate engineering curricula. It is hard to imagine that a serious exploitation of the wonders of the natural world could be contemplated without some understanding of the mechanisms involved in Darwinian evolution and by extension how we think about engineering design.

Conclusions

The evolutionary perspective presented in this chapter is not a rejection of the teleological process observed in engineering design but rather a statement that design is an "individual, solitary, and often after heroic activity, ending in a final and supposedly perfect result", and is at best an exception and not the rule (Yagou, 2005). Further, many of the characteristics that are associated with biological evolution are useful metaphors for many aspects of engineering design. From an educational viewpoint by including an evolutionary understanding of design, students should be enabled to place their efforts in a more general context encouraging a humbler attitude that helps in the development of being a good team player – a valued attribute in engineering bearing in mind the often multidisciplinary and heterogeneous nature of design teams (Yagou, 2005).

As part of an integrated studies approach, a historical treatment of engineering, science and technology, in particular with respect to design, that includes an evolutionary account coupled with themes picked up in technical subjects, could lead to a deeper understanding of how designs come to be and how designs are subsequently developed. Whilst the engineering literature is not rich in terms of pointing out the relevance of evolutionary theories to designed objects more general accounts are available (Dawkins, 1986; Michl, 2002). In the sense of a Liberal Education as discussed in Chapter 8 the reading of the books by Dawkins and Dennett, to name just two who have been to the forefront in explaining the relevance of Darwin, would be a good input to educating an engineer in the richness of evolution. To those could be added the works of biologists Peter Medawar and Stephen Gould who have written about technology from an evolutionary perspective.

To conclude, "if anybody were to start where Adam started, he would not get further than Adam did" a quotation given by Jan Michl and attributed to the philosopher Karl Popper (Michl, 2002). This is another and more direct way of stating what Newton expressed in his 1676 letter to Hooke.

References

Christensen, S.H., Meganck M., and Delahousse, B. eds., 2007. *Philosophy in Engineering.* Aarhus: Academica.

Darwin, C.R., 1859. *The Origin of Species by Means of Natural Selection, or, the Preservation of Favoured Races in the Struggle for Life.* 6th Edition quoted. Available on-line.

Dawkins, R., 1986. *The Selfish Gene.* Second Edition. Oxford University Press.

Dawkins, R., 1996. *The Blind Watchmaker.* 3rd Edition. WW Norton & Company.

Dennett, D.C., 1996. *Darwin's Dangerous Idea: Evolution and the Meanings of Life.* Simon & Schuster.

Gould, S.J., 2007. *Punctuated Equilibrium.* Harvard University Press.

Kuhn, T., 1962. *The Structure of Scientific Revolutions.* University of Chicago Press.

Langrish, J.Z., 1999. Different Types of Memes: Recipemes, Selectemes and Explanemes. *Journal of Memetics – Evolutionary Models of Information Transmission.* Vol 3.

Michl, J., 2002. On Seeing Design as Redesign: An Exploration of a Neglected Problem in Design Education. *Scandinavian Journal of Design History,* 12, pp.7-23.

Mueller, T., 2008. *Biomimetics: Design by Nature. What has fins like a whale, skin like a lizard, and eyes like a moth? The future of engineering.* Available at: http://ngm.national geographic.com/2008/04/biomimetics/tom-mueller-text.

Ochsendorf, J.A., 2005. *Engineering in the Andes Mountains: History and Design of Inca Suspension Bridges.* Library of Congress webcast. Available at http://www.loc.gov/today/cyberlc/feature_wdesc.php?rec=3839. Downloaded 25 January 2009.

Ogot, M., 2004. *EMS Models: Adaptation Of Engineering Design Black-Box Models For Use In TRIZ.* Proceedings of ETRIA TRIZ Futures 2004 Conference, Florence, November 2004.

Petroski, H., 1985. *To Engineer Is Human: The Role of Failure in Successful Design.* St Martin's Press.

Petroski, H., 1996. *Invention by Design; How Engineers Get from Thought to Thing.* Harvard University Press.

Richardson R, 2002. *Engineering Design and Adaption.* Phil. Of Science Assoc. 18th Biennial meeting. Milwaukee.

The TRIZ Journal. Online: http://www.triz-journal.com/whatistriz_orig.htm

Vermaas, P., Kroes, P., Light, A. and Moore, S., 2008. *Philosophy and Design: From Engineering to Architecture.* Springer.

Vincent, M.B., Madhaven, G., and McLeod, K., 2006. *Evolution as a metaphor for Design in Engineering Programs.* ASEE Conference.