HISTORY, PHILOSOPHY AND THE CHANGING NATURE OF ENGINEERING

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INTRODUCTION

The changing nature of engineering demands a new approach to the history and philosophy of engineering. Recent innovations present analysts with an inter-related set of historical, philosophical and engineering problems which must be solved if continued engineering progress is to be facilitated. Present-day strategic engineering design compels engineers to create an internalist history, and an internalist philosophy of engineering for themselves, granted the neglect of internalism by most historians and philosophers of technology, whose goals and priorities are different, and whose engineering skills are inadequate for this task.

History and philosophy of engineering are distinct from history and philosophy of technology as the latter are generally understood in the 1990s, though they can be related. No adverse criticism of historians and philosophers of technology is implied. The author has a different aim from them, which is to confront problems in engineering requiring the methods of historical, philosophical and engineering analysis for solution. His goal is to serve engineering by analysing the changing nature of those strategic components and systems which define what is meant by exemplary technology in the late 21st century.

STRATEGIC INNOVATION

Strategic engineering innovations set new standards for determining what is meant by modern engineering at its best. They introduce the engineering components and systems on which new industries are founded.

During each era, relatively few industries set the global standards, and lead industrial and economic growth. Each of these industries depends on a particular engineering system, or combination of systems, which represent the best practice for that time. These new engineering systems deepen, broaden and transform contemporary understanding of what engineering is, with consequences for industry, education and culture. Of particular importance are those innovations which result in a period of global economic growth. Identifying the strategic engineering innovations in different periods, and different cultures, is a major task for historians.

In each period there are artefacts, systems, theories, and methods which are associated with technologies which originated in different periods. Amongst these will be those devices and methods which call into existence new industries, with new standards of training, education, funding, organisation, management, production, construction, and research. They introduce new ways of thinking about engineering and its physical and cultural environments, and they cannot be understood without directing attention to the conceptual apparatus, symbolism, and language by which they are defined, analysed and described.

Today, in such fields as artificial intelligence, virtual reality engineering, and engineering studies of perception, the abstract conceptual apparatus is as much an engineering artefact as the tangible, material equipment. Engineering innovation is creating new concepts and models for interpreting human experience and physical phenomena and engineering has become a creative science second to none.

Most carefully classified analytical studies of engineering innovation concentrate on the post-1600 period, in part because they have been carried out by innovation analysts and economists seeking a deeper understanding of the world built by mechanised industrial-capitalism. Much needs to be done on earlier periods to compile detailed histories of the engineering innovations during the Classical and Medieval epochs in Europe, and in the great civilisations of North Africa, the Near East, and Asia. By its very nature, an innovation has to be perceived as such.

It is a recognisable " event " or development, which becomes easier to define, and analyse after 1600, when relatively rapid changes in equipment form, within the life of an engineer, enable innovation to be identified as a distinct activity. It is questionable whether one can refer to innovation in the ages when mankind's ancestors were evolving, and learning to use simple implements without the philosophy, language and ideas to understand them.

A much deeper insight will be gained into the evolution of engineering when more is known about developments in the pre-written language period, and when more has been done on the first correlations between technical developments and corresponding developments in language, symbolism and philosophy.

Through the lack of such studies, too much attention has been directed onto " engineering as objects " rather than onto " engineering as ideas ".

EXEMPLARY INNOVATIONS

Identifying the exemplary innovations and the standards-setting technical systems which are found in the great civilisations enables the path of engineering progress to be traced through a thousand years of complex social and economic change. Engineering exemplars may be likened to paradigms, a concept which originated in grammar, and which was used by C.G. Lichtenberg in the 18th century, and which was developed in the 1960s by T.S. Kuhn in his study of conceptual revolutions in science. Studying the rise and fall of strategic technologies, and their influence on economic growth, shows that the nature of engineering artefacts and engineering method has changed considerably since 1600.

The 17th century can be taken as being the period when scientific engineering, as an intrinsically progressive, distinct activity came into being. Completely new engineering achievements, such as the steam engines and powered textile mills of the 18th century, surpassed those of former civilisations and implanted the idea of technological change. No longer did centuries-old designs, taken from drawings of Roman machinery, continue to guide engineers more than twelve hundred years after the Empire fell.

In the mid-18th century, engineers expected noticeable improvement in their lifetimes. In the 19th century, constant improvement even in conservative engineering was taken for granted. Today, in microelectronics, computing, robotics, nanotechnology, and other exemplary fields, major problems are caused by the need to keep pace with innovation, and to integrate advances made in several disciplines. Modern engineering can now transform itself rapidly.

There is insufficient space here to list the more important exemplary innovations in the history of engineering from circa 250,000 BC. Any such attempt raises the question as to what is meant by engineering in the periods before language, systematic thinking, and systematic symbolism. The stone axe of 250,000 BC is an artefact made by early man, but how was the process of manufacture recognised, remembered, co-ordinated with mental activity ? When did manufacture become a conscious, recognised activity ? An exemplary device from much later, circa 3500 BC, such as a four-wheeled steppe wagon, or the spoked-wheeled Chinese chariot of *c.* 1000 BC raise the question of how to assess the ability of their builders to imagine devices ; to criticise them in the imagination ; to idealise them ; to conceive of a better design after which they could strive.

Engineering history will remain defective until studies of the use of symbols, ideas and imaginary models in technics are carried out. This will demand going far beyond the activities thought proper for most " history of engineering " societies at the present time. The author believes that what we mean by modern engineering method, with its integration of imagination, idealisation, and insight gained by rational observation, analysis and experiment, becomes a major source of innovation and industrial change in the 17th century, though it is discernible much earlier. Identifying some of the exemplary innovations in each century witnesses to the changing nature of engineering.

The man-powered organ bellows ; the 15th century Duringer clock ; the water-driven fulling mill ; the 17th century Savery steam engine ; the 18th century Newcomen engine ; the 19th century steam locomotive ; the 19th century telephone, electric motor, or power station ; the 20th century wireless telegraph, broadcasting system, totalisator, computer-controlled signalling network, electronic code breaking system, virtual reality system, or microprocessor implanted into a cockroaches back : each represents best practice in a particular culture in a particular age. As we approach the present, the devices depend more and more on imagination, abstraction, and the use of evolving conceptual apparatus, and analytical tools, for their creation. Their span of usefulness shortens, and calls for historians able to deal with the events of the last five years. This challenge will hardly appeal to those historians who turn to history, including history of engineering, to escape from the present.

The role of innovations in the industrial-capitalist epoch can be briefly summarised as follows. The Newcomen atmospheric steam engine of the early 18th century marked the start of a mechanised industrial society which evolved through innovation, and accelerated the pace of its own expanding development, though admitting this does not deny the innovative achievements of earlier times. There have been distinct phases of growth in the global economy dominated by engineering change, and its consequences. Economists argue that each distinct phase is begun by engineering innovation. The Newcomen engine, the Crompton " mule ", the Darby coking oven, and water-powered machinery, transformed the industrial process and enabled it to expand. These strategic innovations created the strategic industries during the first period.

During periods of growth, a limited number of industries, based on engineering innovations of equal degrees of modernity, interact and stimulate each other. They foster exchanges of ideas, practice, products and staff. Growth industries serve as markets for other growth industries. Sometimes this group of strategic industries may be dominated by one — the " grand exemplar " — which best of all others exemplifies the vision, science, technology, organisation, quality of workforce, research initiative and other qualities which the others emulate. The influence of this group extends far beyond itself to the many small industries and businesses which depend on it ; to the worlds of education and training ; to commerce ; to public administration and politics ; and to popular culture.

During growth periods, available funds flow into these industries, but a time comes when they become less fruitful, perhaps because their technologies become obsolete. The industry itself might continue to be economically important, as was the British textile industry after 1890, without being a source of strategically significant innovations of a world-transforming class. Such industries are vulnerable to any better equipped, better organised modern rival. Available capital, seeking maximised returns should be moved into the innovations which are creating the strategic industries of the next phase. The geographical location of the strategic industries often shifts from epoch to epoch.

Innovation & Industrial Growth

One common classification of the main epochs is as follows.

The first period was created by the engineering innovations in the textile, coal and iron industries, and was caused by using water and steam power to drive automatic and semi-automatic machinery which greatly increased output per worker. During this period, perhaps the most important strategic activity was building up expertise in application of steam power. This textile, coal and iron " revolution " took place in Great Britain which enjoyed an expertise in strategic skills not easily overtaken by rival countries at that time.

The second phase was dominated by the steam railway, with its attendant industries and services, which generated new ideas, methods and services which further transformed society. Because many of the strategic technologies of this " Railway Age " evolved from those found during the first period, Great Britain continued to be the leading industrial nation.

The third period began with the advent of heavy-duty industrial electrification, dominated by traction, the growth of the motor-car industry, and the introduction of industries and services dependent on systematic research : wireless telegraphy, chemicals manufacture and aviation. The engineering initiative, and leadership in strategic industries passed to the United States and Germany.

A fourth phase was introduced by the innovations of the 1939-1945 war and its immediate aftermath : electronics, advanced aviation, rocketry, nuclear power, computing and telecommunications.

A fifth era has been introduced by nanotechnology, advanced bioengineering, very large scale integrated electronics systems, information technology, advanced robotics, virtual reality systems and artificial intelligence systems.

Engineering studies of the brain, mind and consciousness promise further revolutionary and fundamental changes, not least in mankind's self understanding. In each of these epochs, the strategic innovations, and the industries founded on them, changed contemporary understanding of engineering. The Arkwright water frame (a water-driven machine for spinning threads), and the Crompton " mule " (a hybrid machine for cotton spinning), became major components in the integrated factory system, and were mechanisms which represented a new order of complexity and productivity. The steam-railway developed the concept of machine-ensemble in the systems context, and exemplified the large, influential, financially powerful public institution dominated by private capital. The electric power industry introduced the large, integrated, quantifiable system which required advanced scientific techniques for its construction, for its daily operations, and for anticipating the future demands placed on it. Electrification was widely hailed as marking a transformation in the nature of history and civilisation. In the post-war era, the electronic computer has transformed virtually every activity. Further developments based on electronics and new materials have introduced nanoengineering, artificial intelligence, machine intelligence, and virtual reality systems which have created new industries, dependent on a new kind of engineer.

The engineering innovations demand innovations in education, training and professional organisation. Attitudes to engineering, the profession, and to education and training date from the second and third epochs mentioned above, and were defined through a response to systems which are no longer strategic and exemplary.

Developments in the fourth epoch have led to considerable changes in the engineering profession, and in education, but continuing radical transformations will be required to accommodate the innovations of the coming century when the strategic engineering systems may result from integrating neuroscience, evolutionary genetics, computer science, microelectronics, nanoengineering, molecular physics and quantum mechanics. These innovations will transform public understanding of engineering, and will create industries very different from those which dominated global economics in the past.

ENGINEERING METHOD

The nature of engineering cannot be understood unless engineering method is defined, and unless conceptual apparatus, and methods of analysing engineering systems, are considered equally with the disposition of components within an engineering ensemble. Putting it simply, engineering method is a particular case of scientific method, which thereby involves the creation of concepts, models, and methods based on observation and checked by experiment, which relate precepts and correlate sets of ordered sense-data. These concepts are employed to interpret idealised systems which can be analysed in thought-experiments prior to being used to guide the design and construction of some concrete equipment or system. Experience with the actual, realised system leads to its performance being observed, measured and modelled. The model of actual performance is compared with the model of expected performance, which is probably different from the model of ideal performance. A model of improved performance is created, which in turn guides a second realisation of a better actual device, and so on, with successive approaches to the ideal until an actual device, good enough for commercial and industrial success, is obtained. This creation of various sets of model — the experimental based on experience and observation — and the ideal — based on imaginative thought-experiment — are associated with an ongoing comparison between the two sets of model. An imaginary system, abstracted from the actual, is thereby progressively perfected by approximating to an ideal, and is repeatedly used to improve design and production of better realised types : the actual machines. But the ideal is not static, and it evolves as knowledge increases.

All engineering creations have to fit into a larger " receiving system ". Each original design is conceived within a defining envelope, and there needs to be a model of the interface with the receiving system into which the actualised technology must fit. This receiving system changes all the time. It may be a radio broadcasting system ; a system of food production ; a telecommunications network ; a marine engine ; a microprocessor component, or a piece of domestic equipment, but the new component (which may be a system in itself) must interface with it, and the connecting relations have to be defined at outset with sufficient clarity to ensure that the component will function efficiently in its environment.

The overall process of design and integration involves fitting two systems together, the engineering component, and the receiving system, each of which changes in ways requiring endless modelling. Some components and systems can be described almost entirely in quantifiable, engineering terms, but difficulties arise when the design embraces vast systems where it is not possible to assign parameters to the defining envelope or the interface between component and receiving system. This is particularly the case where system parameters (such as fuel price, or labour costs) are subject to non-predictable changes. However, as engineering has developed, the analytical methods, and the conceptual apparatus for detailing and quantifying the above process, have become more extensive and in some cases more accurate, especially in research and development, and in narrowly technical environments. Despite ambitious programs in the USA, and to a lesser extent in Europe, attempts to model the general economic receiving system into which new technologies fit have not been successful.

Engineering Analysis & Conceptual Apparatus

The changing nature of engineering is displayed in the increasing importance of the analytical tools ; the conceptual apparatus ; and the techniques for modelling actual, abstract and ideal engineering systems. The engineering systems which were exemplary in former ages could often be constructed without an integrated system of abstract models, supported by mathematical analysis, scientific experiment and quantification.

Examples include Medieval bell founding and organ building ; 17th century military engineering ; and much 18th century civil engineering — like lighthouse building. The construction of canals and wagon ways in the 18th century ; and the construction of railways before 1830 did not demand integrated systems of mathematical analysis, though they demanded — and got —

a great deal of Enlightenment science and reason applied to industrial problems. But after 1870, there is a marked increase in the perfecting of engineering method as defined above. Without very advanced mathematics, there could have been no industrial electrical engineering ; no commercial wireless telegraphy or broadcasting ; no aviation. Without science, and rational analysis, there could be no chemicals industry ; no mass production ; no modern materials. The trend is towards increasing reliance on analytical tools ; modern mathematics ; abstract modelling and thought experiment, which suggest new technologies, and indicate how links might be established between departments of engineering, science and other disciplines once thought quite disconnected. There is no longer an excuse for thinking of engineering in terms of matter alone : it is now, in its exemplary departments, much more a matter of mind.

Engineering always disclosed relationships between abstract concepts, and many devices were created through efforts to embody in mechanism properties which were metaphysical, occult, or abstract. Shifting the goal from occult to rational-abstract underlies engineering design as it evolved between the 13th century and the 19th century.

In the 13th century, it was common to try to reproduce in mechanism an ideal attribute observed in nature, such as the perpetual motion of the spheres. The gradual separation of metaphysics, alchemy and the rational-physical led to the scientific study of mechanisms which modelled physical actions mechanically, though ridding science and engineering of occult notions was a very slow business.

In the 17th century, a rational, mechanical philosophy triumphed to exercise a general influence throughout mechanised, industrial culture. In a brief paper such as this one or two examples must suffice. The evolution of musical instruments, and the design of clockwork, embodied metaphysics and philosophy, though few histories of engineering bring this out.

Museums nearly always display machinery in terms of visible actions rather than expressions of ideas. Consider the astronomical clocks, built by Hans Duringer, such as the one being restored in St. Mary's Church, Gdansk, Poland. Built between 1464 and 1470, this device is a philosophical machine which replicates in mechanism the ideal motion of the celestial bodies. Much of 18th and 19th centuries engineering development was profoundly influenced by Enlightenment philosophy, as was recognised at the time. Lazare Carnot (and F. Reuleaux) analysed mechanisms in terms of the fitness and harmony of components and constructs which mirrored the harmony of the physical order. The imaginary, idealised heat engine of Sadi Carnot, is an example of a disclosing model, which established a relationship between the imaginary and ideal, and the actual and imperfect. Thought-experiments conducted with it helped to show the ways by which designs could be improved. Thought-experiments conducted with an imaginary engineering disclosing model, abstracted from the actual piston-and-cylinder atmospheric engines of Huygens and

Papin, enabled Brillouin to investigate the Maxwell " Sorting Demon ", and to establish a relationship between entropy and information exchange.

The role of engineering devices, many of them found in industry, in stimulating the imaginary disclosing model has been almost totally ignored, yet imaginary devices, suggested by industrial equipment, have led to great advances in conceptual apparatus. In order to improve electric motor design, and solve network problems, G. Kron created an idealised universal motor, and a system of analysis which relied heavily of imaginary entities, and resulted in an ambitious scheme for geometrising engineering. He did much to introduce tensors into engineering, and devised a general method of analysing and ensemble with mechanical or electrical elements, which he termed *Diakoptics*. Kronts work, and the vast conceptual apparatus demanded by electrical engineering is seldom featured to any extent in histories of electrical engineering. It is admittedly difficult to link the conceptual to the actual, for instance in a museum, but unless the effort to do so is made, the simple narrative history, or the museum display, are incomplete and possibly grossly misleading.

The management, organisational and production theories of F.W. Taylor, H.L. Gantt, F.W. Gilbreth, and H. Ford sought to incorporate in industrial activities the order and harmony which 19th and early 20th centuries science found in the physical universe. The work of Taylor and other pioneers of rational or scientific management mark the rise to importance in engineering of theories of organisation which became as important as theories of materials failure.

Exemplars in Modern Engineering

Current developments show how much engineering has changed since the 1960s when " best practice " was represented by a Saturn rocket, the Dounreay Fast Breeder Nuclear Reactor, the early satellites, or the first solid-state electronics systems. The work of Professor Cochrane and his team, at the Martlesham Heath laboratories of British Telecommunications, suggests that in the 21st century it may be possible to interface silicon chips with the human brain, perhaps by developing the equivalent of nerve endings on the chips. If this proves possible, the carbon-based memory systems of the biological brains, which have evolved on Earth, could be linked to the silicon-based systems of information technology. Perhaps the capacity of the human brain could be considerably increased sufficiently to mark a discontinuity in the evolutionary progress of mankind and herald the advent of a radically new bio-technical ensemble.

The developments in virtual reality engineering, artificial intelligence, and other modern disciplines require for their understanding a considerable degree of philosophy in addition to some familiarity with cognition studies, neuroscience, psychology and information technology. The response by engineering schools will need to be profound and extensive. The work of Prof. J.O. Gray into advanced robotics at Salford University uses technologies for simulating the sensed movements through perceived but imaginary environments. Imaginary surfaces can be touched using the Uttal Glove. Imaginary environments can be visualised and explored. Experience with these innovations raises questions concerning the ontological status of precepts, concepts, mental constructs, visual images, imaginary and actual entities. It prompts users to ask what is meant by reality, and how it is defined and recognised. These new systems suggest new ways by which human perception of the spatio-temporal environment might be interpreted.

The virtual reality systems, which simulate imaginary environments, stimulates questions from students about matters which out of date educators regard as the concern of philosophers only. Today, questions concerning consciousness, perception, ontological status of the perceiver and the perceived, and the meaning of " reality " are asked by engineers working in advanced areas of their discipline. Engineers routinely study intelligence, the nature of mind and the nature of life (artificial and biological) to improve further the fields of control, robotics, neuroscience and artificial intelligence. Artificial Life is one of the latest subjects to be listed in the publications of Oxford University Press, where the proceedings of the Tufts Symposium examines the relationships between Darwinism and Artificial Intelligence, drawing on Biology, Cognitive Science, Mathematical Genetics, Philosophy of Science and of course AI.

In other areas engineers are examining the intelligence and control systems of insects and other life forms, to assist the developments of control systems in robots. The analysis of Artificial Intelligence and Artificial Life demands a comparison of different kinds of life form, and different levels of intelligence as they have evolved. Links between once-separated disciplines are creating new disciplines and changing the nature of engineering in the late 20th century. In the last year, a Japanese mechanical engineer removed the wings from cockroaches and implanted microprocessors in their backs to control their movements. Telecommunications engineers have interfaced a rat's brain with a microprocessor and monitored its neuronal activity — using electron microscopy to take pictures. The nature of self-awareness is now a matter of serious discussion.

The work of Prof. Igor Aleksander, of the Electrical Engineering Department, Imperial College, London, involves exploring engineering definitions of intelligence, and asking which are the characteristics a system would need to exhibit for it to be termed intelligent, perhaps even termed self-aware. Engineering departments developing computers and robots now employ psychologists to help formulate problems in machine-perception to improve the ability of robots to recognise things. Engineers study consciousness and the working of the brain with technical applications in mind.

PHILOSOPHY, HISTORY & ENGINEERING

Philosophical matters need to be considered if engineering design is to be competently executed. Likewise, a new kind of historian is needed, able to analyse very recent developments and to serve a design team working on contemporary problems.

The life cycle of some recent technologies is a few years or months, and historians cannot restrict themselves to the events predating their birth or 30 years ago : too much has happened in the last five years which demands analysis, classification and interpretation. These historians will also need to be philosophers to understand the nature of the changes which they describe. Philosophers will also be needed in the education of engineers to prepare them for their duties in the next century. The links which are established between disciplines once remote from each other are connecting such subjects as evolutionary genetics ; engineering studies of the brain ; neuroscience ; intelligence ; information theory ; and bioengineering. There is attempted integration with modern theories of matter, and theories of how material ensembles can evolve and program themselves.

A comprehensive and powerful system for interpreting mankind in scientific, physical terms is being created with capacities much greater than the models used by Philosophical Materialism in the past. Indeed, Philosophical Materialism is undergoing a great revival and the cultural consequences will be considerable, not least for revealed, supernaturalist religions, and traditional systems of morality, ethics and socio-political organisation.

The philosophical discourses concerning the nature of things, and the possibility that man is a machine, associated with Enlightenment savants like La Mettrie, or D'Holbach, and which became a continual theme in 19^{th} and 20^{th} centuries humanism and freethought, remain vital issues. Today, they are kept alive as much by engineering developments as by developments in physics and biotechnology. Consequently, they are issues being spread throughout society.

Modern technology, in all its forms, is forcing a far wider section of society to consider such questions than ever did before. In the next century developments in artificial intelligence, artificial life, bio-engineering interfacing, and virtual reality — to name but a few areas where considerable development can be anticipated — will compel many to ask the question " What are we ? ".

Many of the author's students accept that human beings are very advanced, self-programming biological machines which have evolved and, using their own engineering abilities, will plan further, increasingly rapid development of the species with increased lifespan, and enhanced intelligence. That so many take this for granted is one cultural consequence of the changing nature of engineering.

DEVELOPING THE HISTORY OF ENGINEERING

It behoves all historians of engineering to ask what will be the impact of these developments on their discipline. The author believes that a radical and comprehensive development of those activities labelled " history of engineering " is required if an adequate account of the evolution of engineering from origins to present is to be compiled. History of engineering as it stands now is defective, incomplete and misleading, through a neglect of the methods and the conceptual apparatus of engineering, and a persistent failure to analyse engineering artefacts as embodiments of ideas. An overconcentration on equipmental form has resulted in too many detailed chronologies being passed off as history.

The general failure of professional historians and philosophers to understand engineering means that the few (very few) attempts from their ranks to tackle the problem fall short of what is required. History of engineering must start with engineering. No-one who does not understand engineering method, and who cannot solve engineering problems can write the mature engineering history which contemporary engineering requires. They might well write sound industrial archaeology, or conduct social studies of engineering communities, or compile histories of the consequences of engineering innovation on culture, but it is most unlikely that they will be able to do justice to history of engineering. The author suggests that engineers should take up the challenge themselves. Engineers, who have mastered the methods of conducting historical enquiry as a professional historian understands them, should direct their own program, working closely with the professional institutions and engineering centres in universities. They will need to work with historians and philosophers, and become professional in history and philosophy, but they must retain control of their own program and not assume that the people best suited to direct history and philosophy of engineering are historians or philosophers from outside. They are not. In the main, historians and philosophers share too many misconceptions about engineering to be of much help, though there are noteworthy exceptions. Besides, the coming together of many developments, rooted in engineering change, is so revolutionary that it is best to make a fresh start. Too many disciplines which matured before the recent wave of radical innovations lack the insights, and flexibility of mind, to respond to the challenge quickly enough. They are too conservative, and rooted in a culture which scientific-technological change is rendering meaningless.

The crisis in internalist history and philosophy of engineering is exacerbated because the tools for investigating it have to be forged rapidly in the face of rapid transformation of the nature of the object of study. Rather than try to use the methods of history of engineering as it is now, or to borrow from other departments of history, it is better to start anew, independent of those organisations (mainly learned societies and clubs) which at present claim expertise in history and philosophy of engineering.

The first thing to do is to recognise what modern engineering is, and to devise methods, concepts and constructs for defining the nature of engineering as represented by the most recent exemplars. These exemplars will need to be distinguished from those components and systems which originated in different eras. The several lines of evolution by which the different classes of engineering have evolved require tracing, with as much attention being given to conceptual apparatus and formative ideas as to equipmental form. An analytical, conceptualised history covering the developments of several millennia will be needed to chart how the nature of engineering has changed since activities worthy of the name " engineering " first appear in history. The concepts, theories, components and systems needed to understand modern engineering as represented by artificial intelligence, nanoengineering, virtual reality systems, or advanced robotics, indicate that engineering cannot be studied without recognising it as an expression of mind. To understand it requires an analytical, conceptualised history of change, and a philosophy to classify the nature of the changes.

Once this is grasped, the next step is to construct an adequate history and philosophy of engineering which traces the evolution of the many strands of engineering development through their major stages from the origins of human thought, or from an earlier period before the emergence of philosophy and articulate language. Recognising what engineering has become today will indicate which activities in the distant past will need to be studied, though every care must be taken to avoid the errors of " writing history backwards " and projecting modern assessments into previous ages. But much of the current attitudes to engineering are distorted by narrow 19^{th} century prejudices and a tendency of amateur writers to define the nature of engineering through narrative descriptions of the changing forms of industrial equipment. So many learned societies, and history societies are dominated by this erroneous outlook that they are of little use in meeting the challenge modern engineering presents to the historian and philosopher.

Modern engineering has changed our perspective on engineering development, all the way back to the stone axe, and the first correspondence between artefact, mind and symbolic representation. Many of the traditional history of engineering societies are now antiquities, preserving outdated notions of history of engineering formed by amateur industrial archaeologists : they cannot meet the challenge of the recent insights into the nature of engineering which have arisen out of recent innovations.

The required history and philosophy will be internalist : only internalism can provide the engineering insight which alone can lead to adequate methods for analysing the innovations in different periods, so that they can be set in historical perspective. The studies will need to accommodate an expanded innovation analysis which accommodates an endless stream of innovations in the standards setting strategic areas which drive engineering forward. This is why the historians and philosophers required for the task are more likely to be drawn from the ranks of engineers with an enthusiasm for engineering progress than from the schools of history and philosophy as they are organised at present. This is not to say that the engineers can do it all alone, and work in isolation. As remarked above, engineering change is establishing links between engineering and disciplines such as psychology, neuroscience, and cognitive studies. Philosophers and historians working in these disciplines ought to be welcomed as collaborators. Those willing to work with engineers are recognisable by the work they do which carries them naturally towards engineering, just as the engineers (working for instance in AI, or VR) are naturally brought into contact with historians, philosophers, and other professionals in the course of their engineering work. But engineers must make a start themselves, in their own camp, on their own initiative, and prove themselves as engineer-historians and engineer-philosophers, before reaching out to the historians and philosophers developing within other strategic disciplines. They must not begin by turning to the historians and philosophers in the traditional, non-engineering societies.

Once the above steps have been taken, links can be established with historians and philosophers willing to develop history and philosophy in a modern-minded spirit : they will look back to understand the past, to turn towards the present, and to prepare for the future. Their history and philosophy will solve problems as well as deepen insight and extend knowledge. Much of existing history of engineering, narrative chronology, and industrial archaeology will be put to good use for the first time by relating them to the history of ideas, without which they remain pointless accumulations of technical facts. Much history of engineering, despite hard work, pedestrian diligence, enthusiasm, and persistence remains a monument to futility because it serves no enlightening end. But if the objects studied by the more competent chronologers of the " amateur " period are set into the evolving background of ideas which created them, and are provided with the philosophical analysis which they require, then much of this sterile history will bear fruit, in some cases long after the death of the compilers.

The new history will liberate historians from an obsession with things and perhaps revolutionise the policy behind accumulating collections in museums. It will begin with history, theories of history, philosophy, and the ever-changing conceptual apparatus by which engineering artefacts are defined, designed, recognised and analysed. When a history of engineering going back to the origins of systematic thinking has been devised, a rational policy for classifying objects, and developing collections may be formulated. Increasingly, within history of engineering, the emphasis will shift towards compiling accurate records of the abstract, the imaginary, and the theoretical attributes of engineering rather than the tangible or concrete equipment which can be seen and touched, because it is these entities which are the vital elements in the new engineering systems. To an engineer working in AI, VR, or cognitive studies, the evolution of mankind's use of language and symbols ; the emergence of perception ; the comparisons of human and animal intelligence set in evolutionary perspective, are likely to be much more important in the development of engineering, and to the understanding of its history, than those subjects found in most history of engineering journals. The emergence of articulate language ; the evolution of thought in relation to the bicameral brain ; and the history of studies of insects' intelligence are likely to become as much part of the history of engineering in the 21st century. as are studies of the Newcomen engine in the history of engineering of the 20th century. Investigators of AI and AL find theories of evolution, mind and genetics as relevant as strength of materials, perhaps more so : therefore the historians of these new departments of engineering will have to study them also. Granted the very rapid pace of innovation, with radical changes taking place within five years, these historians are needed today.

THE ELECTRONIC MUSEUM

Focusing the attention on the abstract, on the conceptual, and on cognitive models within the context of engineering, will be encouraged by the creation of electronic mail, electronic archives, and electronic museums. When there is available a world wide network, able to exchange accurate images of artefacts, and providing access to archives, it should be possible to provide an integrated display of an image set in its philosophical, conceptual and theoretical framework.

Visual representation, pictures, engineering drawings, network diagrams, mathematical analysis, experimental data, etc., could be called up as part of an information package dedicated to that particular item. Computer replication and simulation may make it possible, in the near future, for the historian to explore electronically created replicas of any kind of device or system collected in the electronic museum. Designs could be analysed, inspected, taken apart, operated, and understood in a way simply not possible with actual hardware replicas. The analysis, using computer replication, could be extended to bio-technical ensembles, such as the microprocessor implanted into a rat's brain ; or into simulations of the small scale interiors of nanoengineering systems, or into the depths of " Colossus ". Granted the anticipated improvements to electronics information systems of all kinds, there does not seem to be any reason why replicas and models of engineering systems from any period should not be created and stored within electronics museums. This will help concentrate attention on history of engineering as " knowledge and ideas ", relying on sound analysis, drawing on good records and archives. The global electronics-mail museum, using virtual reality systems, would present images of artefacts in such a way that the connection between visual representation of an item and the associated conceptual apparatus and philosophical framework was made evident. This would liberate museum displays from the misleading domination of the perceived object, and render unnecessary the conservation of buildings and machines which had been accurately recorded using electronic means.

The stress should switch from the preservation of objects to the preservation of information. If scholarship and enlightenment are the objects of historical study, much of what is today termed history of engineering is due for a change in every department.

The learned societies will either carry through extensive and painful transformations, and belatedly professionalise themselves, or they will fossilise within an older tradition of amateur history, quite inadequate in the 21st century, and survive as clubs which organise visits and meetings representative of " history as it used to be ". They will become part of the " heritage history " movement. The author believes that a mature history of engineering can only be created by the engineering profession itself. When this has been done, fruitful links can be established with historians and philosophers working within bodies like IUHPS, ICOHTEC, BSPS, SHOT, etc., but not before.