Int. J. Engng Ed. Vol. 8, No. 6, pp. 408–412, 1992
Printed in Great Britain.

0742–0269/91 $3.00+0.00

Engineering History and the Formation of Design Engineers

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It is a curious contradiction that many senior engineers voice their opinion that a knowledge of engineering history is essential to being a good design engineer, yet very few courses in engineering include a study of history in their curricula. The author considers a number of the arguments which have been put forward in favour of studying engineering history and, generally, finds them less than persuasive. He puts forward his own idea that an awareness of history is inextricably linked with the notion of precedent and the ability to evaluate the quality or suitability of previous solutions to engineering design problems. Thus, it is argued, while a knowledge of engineering history cannot be claimed to be necessary for all engineers, those who wish to be excellent designers ignore it at their peril.

INTRODUCTION

IN A VERY real sense we are all historians and are making use of history all the time—our own experience and memory are as essential to our everyday lives as they are to our engineering activities. An awareness of more experience and of more memory—that of our contemporaries and, especially, of our predecessors—must surely, therefore, be of great benefit to us, both as persons and as engineers, if we can only use it. This alone, however, seems not to be an argument of sufficient strength to ensure a place for the study of history in engineering courses.

Engineering design is an art not a science: it is a skill rather than simply the gathering of data and explaining of natural phenomena. It is an art which draws heavily upon engineering science, but draws also upon other bodies of knowledge—an ability to conceive and represent artefacts in three dimensions and to imagine the processes of their manufacture. In common with other arts, engineering design carries with it an (often implicit) wealth of cultural connections including safety, legislation, technology, manual skills and green issues.

It is thus impossible to understand fully engineering design without understanding the culture and society in which it exists and in which it developed; and this includes the most technical aspects of engineering design, as well as those associated with image, style and fashion. What student of painting, architecture, pottery, music, English literature or sculpture would be satisfied with the engineering student's typical awareness of the history in their chosen field of study? Indeed, it could be argued that to study an art *is* to study its history.

* Paper accepted 20 November 1992.

Nevertheless, the last two centuries have seen the growth of ever more mathematical and strictly engineering-scientific education for engineering designers. The cultural aspects of the profession and of the engineer's skills have become more and more neglected. In addition to any consequent loss of quality in engineering design itself, there are some very serious incidental consequences. How many politicians have studied engineering? How many engineering companies are virtually run by non-technical people with backgrounds in marketing or accounting? How many contracts have been lost because of the inadequate social, linguistic and rhetorical skills of specialist (even narrow-minded) engineers? There are many who believe these situations to be due, in part, to the narrow education and formation of engineers.

SOME FALLACIOUS JUSTIFICATIONS FOR STUDYING HISTORY

Argument in any field which involves passion and enthusiasm is accustomed to being tainted with exaggeration and fallacious logic. For instance, despite a friend's observation that 'All the interesting engineers I meet are interested in the history of engineering; the boring ones are not', it cannot, unfortunately, be deduced that studying history makes people interesting. A similar fallacy lies behind the claim that an interest in the present is stimulated by a study of the past. One of many examples of this fallacy is to be found in a recent report on Qualitative Analysis of Structures:

> Over two thirds of the graduates had apparently attended no lectures on the development of structural theory. This is clearly an area which would help to stimulate students' interest in the subject. [1]

Yet another frequent claim is that by studying the experience and, more especially, the accidents and mistakes which befell our ancestors, we will be able to avoid the same errors ourselves. This argument, too, has no logical basis—it is very seldom the case that present problems and circumstances are sufficiently similar to those in the past for any inductive argument to be reliable. Sadly, it is also usually the case that relevant historical precedent is discovered only after a failure. The case of the Taccoma Narrows bridge, which collapsed in the throes of wind-induced oscillations, is typical. After the collapse in 1940, a number of nineteenth-century wind-induced collapses were 'discovered' by the investigation team (engineering historians already knew of them, of course). Even this knowledge, however, would not have prevented the Tacoma Narrows collapse, since, to mention but one of many reasons, wind tunnels were only just being introduced into the research programmes in the aircraft industry, let alone in the (comparatively low-tech) bridge design industry.

There remain two further popular justifications which are given for studying history but which, although worthy, are by no means guaranteed of success and have no logical force behind them:

To gain inspiration by the study of great men

Young people especially, can be inspired by role models, heroes or idols, but it would be unrealistic to assume this to be an important effect in the engineering world, except, perhaps, among the immediate family. We have moved on from Samuel Smiles' well-known biographies of Victorian engineers which were, first and foremost, lessons on the virtues of 'self-help' [2].

To learn humility

Our present age seems to be characterised by a certain arrogance about our place in history. Since the mid-nineteenth century progress has come to be an end in itself and one consequence is the firm, but erroneous, belief that our present achievements, and by inference, our abilities, are greater than at any time in the past. Even a cursory glance at the past will confirm that, nowadays, we have a monopoly of neither extraordinary achievements nor outstanding abilities. Again, however, such an argument cannot be defended on logical grounds.

BENEFITS OF KNOWING SOME HISTORY

A fundamental goal of an engineer must surely be to act intelligently, and it is only possible to act intelligently today with some understanding of our past. Such an understanding is also necessary in order to be able to defend one's choices and actions and to be able to propose new and untried actions with confidence.

Perhaps the most obvious benefits of being aware of the past are to be found simply in knowing what has happened, in order to copy what has been seen to work or to avoid what did not work.

Awareness of precedent

Most engineering is tackling problems which are not new. The past contains a wealth of design and manufacturing solutions which, if used carefully, can be a fruitful source of ideas.

Knowledge of success and failure

Reports about major disasters can have far-reaching effects on design practice in a whole industry (e.g., the Comet air disasters in the 1950s [3]).

'Standing on the shoulders of giants'

Newton was one of several great men who was well aware that his contribution to learning was wholly dependent on the achievements of many before him. Engineers, too, are in this position and can only evaluate their own contribution and importance in the light of past achievements. It is also important to understand which direction 'forward' has been in the past, and is in the present.

Avoiding rumour and untruth

At the most fundamental historical level, an accurate record of historical data is needed. A knowledge of these can avoid such commonly-held erroneous beliefs as the idea that Eiffel's Tower is built of steel and that Whittle invented the jet engine.

At a very practical level, in some branches of engineering there is also the matter of repair, maintenance and refurbishment. Rather unusually amongst the current range of branches of engineering, the structural engineer is constantly faced with the problems of dealing with old artefacts, increasingly so with the growth of the 'heritage industry'. As earlier generations of engineers die out, so younger people must learn and understand the old techniques of design and manufacture in order to be able to repair and maintain them [4, 5, 6]. These facts alone ought to be sufficient to require structural engineers to learn something of the construction techniques and materials they are likely to encounter—a point which has a particular urgency in the present climate in which many clients are keen (albeit sometimes under pressure from planning authorities) to retain, rehabilitate and reuse old buildings, if at all possible.

Although this argument would seem to be obvious, there is plenty of evidence that many old buildings are needlessly demolished, damaged or altered insensitively, without regard to their historical context because clients and architects cannot find structural engineers who have the necessary historical understanding. Often, of course, the client or the architect will not realise that such understanding is desirable or necessary and hence will not know the right questions to ask. Conversely, engineers who lack the necessary understanding will never say they are unable to do a job; rather, they will put forward only those solutions which they feel competent to deal with, even if they are damaging, insensitive or unnecessary. If continuing professional development is to be taken seriously, surely Certification of Competence in the restoration of timber, masonry, cast and wrought iron, steel and reinforced concrete historical structures should have to be acquired by engineers before they are let near a medieval house or a Victorian mill to restore or adapt it for late twentieth-century use.

THE NATURE OF PROGRESS IN ENGINEERING DESIGN

It is sometimes claimed that engineers do not need to know about history because they must look towards the future in order to provide the progress which society demands. This is a very short-sighted attitude. Without a long-term view of what progress is, and the patterns it follows, it is easy to lose an overall sense of the context in which engineering takes place, both relative to other activities and between different branches of engineering. Three widely-held beliefs about progress are, at best, misleading, and at worst, simply wrong:

(1) It is a common belief that history progresses rather like a river, growing as more and more streams add to the main flow. The consequence of this view is the mistaken belief that every development in the past was somehow leading towards our present position, a view which imposes the idea that our present state is, by definition, the best and that all previous positions were, to a greater or lesser extent inferior.
(2) Another common belief would have it that engineering progresses by means of a series of inventions. While some steps of progress have indeed been associated with inventions, the inventions have usually required enormous development by equally ingenious people in order to make them viable. Every invention needs a new design procedure and development programme to achieve successful production although these are seldom recorded in our history books. On the other hand, there has grown a certain romanticism surrounding inventors, and they can become convenient heroes!
(3) There is also the view that developments in scientific theory precede and, indeed, bring about developments in engineering practice. This is, in turn, based on the idea that engineering design is a matter of 'putting theory into practice'—an idea which, under examination, can be shown to be meaningless [7]. Only by studying the separate developments of each of the three strands of engineering history—engineering design, technology and engineering science—can the relationship between the three be understood.

These ideas about history and the nature of design tend to mask important aspects of both subjects. When studied without these preconceptions, engineering progress can be seen to fall broadly into two types: that which results in a gradual evolution of a branch of engineering, and larger fundamental changes—revolutions—which result in a wholly new way of looking at a problem, even a redefinition of the problem itself. It is important to learn to recognise the signs which characterise the end of a line of engineering development and lead to the state of crisis which precedes a revolution in engineering design [7]. Such approaches to engineering history and progress can also illuminate the nature of the design process itself. Far too many engineers nowadays confuse the ability to calculate, using the equations and formulae of engineering science, with the skill of design. This understanding can be particularly developed by a study of the history of engineering design methods and procedures, and their relationship to parallel developments in engineering science and technology.

SOME LESSONS FROM HISTORICAL METHODOLOGY

Hegel reminds us that,

> What experience and history teach is this—that people and governments never have learnt anything from history or acted on principles deduced from it [8].

In order to avoid the nihilism to which this observation could lead, we need to ask ourselves why there might be some truth in it. Two answers are relevant in the present context:

- we are often ignorant of the past;
- we are not taught how to learn from the past.

Those engineers who are aware of the history of their art are also often the ones who are able to draw lessons from it. The lessons which may be drawn from successes and failures have already been mentioned. This can be quite straightforward when a report into a failure exists. It is a more difficult skill when faced with an engineering artefact of any kind, to unlock the engineering knowledge which is contained in that artefact. This is especially so when it involves imagining the nature of the engineering problem, and the intellectual and other tools which were available to the engineer at the time of its design or manufacture. These are skills which can and must be learnt if they are to be useful.

Most of the points mentioned previously relate to technical matters. There are also several issues which touch on what can only be called the character of engineers, and their place in our society and culture. During the Victorian age and in the early part of the present century, this role for the study of history in general, was considered to be extremely important [9, 10].

In the last century it was unquestioned that engineers played an essential and major part in shaping our world and these achievements were, in general, widely publicised in all sectors of society. The same can hardly be said of the late twentieth century. It is widely agreed that the engineer has lost status, both financially and in his standing relative to other professions. This change has arisen both from society's perception of the engineer and the engineers' perception of themselves.

It is in this last area that history can have a role. To some extent, everyone's self-esteem depends on a knowledge of our past, at the level of culture and society, at the family level and in our own work. Over the last 100 years or so, an engineer's education and training has changed from being largely by apprenticeship (and thereby empirical and historically rich) to being largely based in academia (and thereby theoretical and historically poor). Many engineers now see themselves as little more than technicians and calculators—this is demeaning and in need of considerable enrichment: an awareness of engineering history can provide such enrichment [10, 11].

There is an important difference between education in the humanities and in engineering. In the former, in true classical tradition, the skill of rhetoric is still cultivated. This enables students of humanities to put forward their ideas and arguments more effectively, to defend their opinions, to criticise and evaluate alternative proposals and to persuade others to change their minds. By comparison, engineers, who do need these skills in their jobs, are given little opportunity or encouragement to develop such abilities as students. Their ability to persuade hence often relies only on the results of calculations. This can lead to particular problems for structural engineers who so often need to communicate closely with architects who are educated so very firmly in the humanities tradition. Small wonder, also, that engineers often have difficulty in influencing politicians. Historical study can provide useful skills in these areas in two ways, through criticism and the art of persuasion.

Criticism

By studying existing engineering artefacts, students can develop their critical abilities by learning to explain why certain works are good models and others not, and why certain engineers are important in terms of the contributions they have made to their field [13]. In this way, the essential idea of quality can be introduced and young engineers become aware of what the characteristics of good-quality engineering design and production were, and are. Thus, an academic and critical rigour can be introduced which is often lacking among young engineers, in their uncritical acceptance of the current state of the art as if it were unquestionably correct and infallible. This type of awareness and understanding also serves to develop both their self-esteem and confidence.

The art of persuasion

By being encouraged to have to explain where we are (in engineering history), and how we got here, as well as why we did not end up somewhere else, engineers would develop their ability to argue using 'soft' data rather than only numerical data. With these skills of rhetoric they would then also be better able to argue, with confidence, about where they might go in the future and to be able to persuade others of their views.

CONCLUDING REMARKS—WHAT TO DO?

Although it cannot be maintained that a deep knowledge of engineering history is essential for all engineers, it has been argued that there are benefits to be gained. If the aim of engineering education is to create articulate and confident graduates who will wish to continue to improve the quality of engineering design, production and progress in their sector of industry, as well as to seek to raise the status of their profession, then, based on the arguments given above, the author would suggest that it is essential that engineering students should study some history. The questions remain, what sort of history? and how to teach it?

A distinction must be drawn between the methodology of the study of history and the raw material. There would be little point, let alone time, to furnishing students with an encyclopaedic knowledge of the history of design, technology and science, in many branches of engineering. Rather, students should be introduced to different sources of historical data, such as artefacts, the printed (academic) word, periodicals, biographies, official and public records, and so on. The different problems posed by artefacts which survive (e.g., bridges) and those which don't (e.g., machinery) can be discussed. The importance of preservation, libraries and museums can also be discussed and evaluated [14].

In particular, it would be realised that history is an approach to handling information; it can be a way of thought and a means for creating knowledge out of raw factual data. Records and artefacts are primarily valuable for the knowledge they contain, and need to be worked upon using a variety of historical techniques in order to yield up this knowledge.

Since it is always argued that engineering courses are already full, it would be unrealistic to suggest more than a small historical input, at least to begin with. Sometimes, such as in a course introducing the behaviour of engineering materials and structures or the principles of mechanisms, historical examples can be used extensively—they are often easier to 'read' than modern examples. A dedicated historical course of perhaps only ten hours of lectures can introduce a number of case studies from the history of engineering, and illustrate the variety of subject matter and intellectual approaches to the subject. In general, biography is not to be recommended since it usually has a rather low density of intellectually challenging material.

Most importantly, students should be asked to undertake some investigation, probably from secondary sources, in order to develop the skills of selecting and interpreting factual information: even non-engineering topics could be tackled, such as why were factories developed? or How do cities feed themselves? In the technical field, the true complexity of technical developments such as the steam, internal combustion or jet engine, could be studied, rather than treating them as single inventions. This would illustrate the interrelation of technology, design methods and engineering science.

Most importantly, for students in those branches of engineering which involve repair, maintenance and rehabilitation, they would need to derive from their study a confidence in dealing with old materials, artefacts and engineering techniques in such a way that they can deal with the challenges in a sensitive and knowledgeable way.

Finally, the skill of engineering criticism (analogous to the skills of literary and music criticism) can be introduced at all stages of an undergraduate course. It should be the principal process by which an appreciation of skill in engineering design and manufacture is developed, and both self-awareness and self-confidence are built up. Practice can be given on a range of artefacts, some of undisputed excellence, for example 'classics' such as the centrifugal governor or the Pelton wheel, others of lesser quality which may even have failed in service. These skills can then be applied by the students, with rigour and confidence, to their own work.

In ways such as these, both factual knowledge of engineering history and the methods and approaches associated with the study of history can be introduced to engineering students. It is also likely that this type of engineering education will be the more appealing and challenging to students.

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