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Viewpoint: The Need to Upgrade Experiential Learning*

ALAN JENNINGS
Civil Engineering Department, Queens University, Belfast BT7 1NN, UK

Engineering education has always emphasised mathematical and science-based approaches to learning in preference to learning from practical experience despite the importance of the latter in engineering processes. A case is presented for redressing this imbalance in which it is suggested that experiential learning should be planned into engineering curricula and given, as much as possible, in the form of student-centred learning exercises. One such exercise carried out at Queen's University is given as an example which could be used in the first year of a course. Apart from improving the overall education of students, this should provide a better preparation for considering judgmental and human factors—a change of emphasis which is likely to be needed within the engineering profession as more use is made of information technology, and more reliance can be placed on computer packages to assist with technical considerations.

INTRODUCTION

IS ENGINEERING education timeless or does it need to respond to changes in the social and technological environment? This is a question of growing importance as more and more pressures for change arise viz:

- increasing participation rates in higher education;
- restrictions on university funding leading to lower staff/student ratios;
- changing work patterns of engineers;
- attempts at quality assurance which are provoking more introspection within higher education.

If engineering education is perceived as timeless and near perfect, pressures for change should be resisted as much as possible. However, if it is seen to be inadequate in providing the most appropriate foundation for future engineers performing their anticipated roles, it is essential that opportunities for change should be grasped and steered to achieve maximum benefit. Central to such considerations must be the identification of present weaknesses and desirable objectives. This paper is intended as a contribution to the debate on the direction of engineering education. The suggestion is made that the scientific approach through engineering principles, so dominant over recent years, should now give way, to some extent, to experiential learning emphasising judgmental and human factors.

TECHNOLOGICAL CHANGE

> Telford in 1824 stated his objective in improving the Holyhead road was 'that horses may easily and rapidly trot over the whole range, ascending or descending with a loaded coach' maintaining an average speed of 8 miles/hour [1].

It is difficult to imagine what life was like 200 years ago because the industrial revolution and its aftermath has had such a major effect on transportation, communication, commerce, health, warfare, sport, leisure activities, the physical environment, etc. Within a working lifetime there has been a 'computer revolution'. In the 1950's the 'electronic brain' used to be the butt of the cartoonist who depicted a massively complicated valve-driven device such as the Manchester prototype machine (Fig. 1) producing a stupidly ridiculous answer to a simple question. Nowadays such cartoons would not be appreciated because the man in the street knows that amazingly small microchips can perform defined tasks many orders of magnitude faster and more reliably than humans. Indeed computers have made log tables, slide rules, mechanical calculators and typewriters all obsolete.

As events anywhere on or off the globe become immediate world-wide news and the Internet facilitates greater volumes of communication than was possible with speech conveyed down a telephone line, the impetus for greatest change is in relation to communication. The computer revolution is thus becoming part of an even larger information technology (IT) revolution.

Since light rather than heavy engineering is involved, the IT revolution is spreading much more rapidly than the industrial revolution did in its day. It is much easier to install a small computer and link up to a telephone line than it ever was to construct a canal, railway or mill factory. The effectiveness of employing IT can make a large difference to the competitiveness of manufacturing and commercial organisations. Furthermore the IT revolution is eliminating

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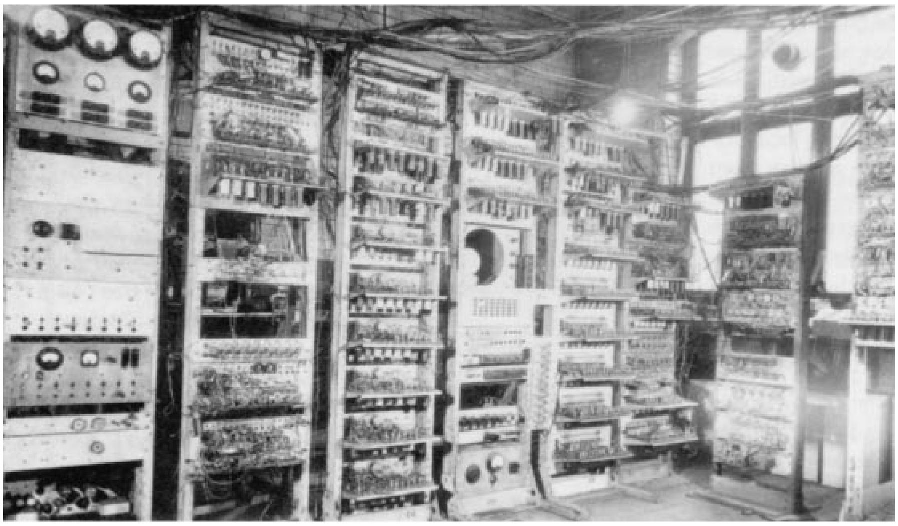

Fig. 1. The prototype for the Manchester Mk1 computer.

jobs which are semi-skilled involving, for instance, repetitive clerical work or supervision of manufacturing processes. Thus IT is contributing to crises in both national economies and employment. Large changes in employment patterns cannot take place overnight, particularly where it is manual and semi-skilled jobs needing to be replaced by skilled jobs.

Universities, if once considered to be ivory towers immune from the pressures of the world round about, are now seen as having a vital role in producing an improvement in skills levels. They are finding that they are being required to educate a larger proportion of the population with less resources per student and to prepare them for a world of employment in which the one certainty is that there will be change. Thus engineering education, along with other forms of education, is under pressure to change due in many ways to the success of engineering itself.

THE SCIENTIFIC APPROACH TO ENGINEERING EDUCATION

The purpose of the engineering sciences is not to record 'laws of nature' but to state relations amongst measurable properties—length, weight, temperature, velocity and the like—to permit a technological system to be analysed mathematically [2].

Engineering development has been inextricably linked with scientific discoveries to such an extent that many pioneers can be claimed as both scientists and engineers. As a result the public often fails to differentiate between science and engineering. (It is well known that a successful rocket trip to the moon may be heralded as a scientific success whereas an unsuccessful one may be dubbed as an engineering failure!) Engineering education can first be recognised in France where 'by 1720, artillery schools had been opened in several French garrison towns, where cadets were given a grounding in algebra, geometry, trigonometry and engineering mechanics' [2]. The emphasis on mathematics and scientific methods has not only continued but has been increased in the twentieth century even to the extent that university faculties concerned with engineering have often been titled 'applied science'.

Advances in science-based methodology in one area of engineering, namely structural analysis are briefly summarised in Table 1 [3]. (Historical developments in structural analysis may be identified in more detail by consulting texts such as

Table 1. A table showing some of the major historic developments in structural analysis and design

Analytic and design techniques	Tools	Approximate period	Leading proponents	Types of applicable structures	Celebrated examples
Not known	Word of mouth	Till 1850	Master masons	Compression	Pont du Gard /Chartres Cathedral
Graphics	Draughting equipment	1800–1920	Culmann	Truss	Forth Rail Bridge/ Eiffel Tower
Diff. equations	Differential calculus	1820–1970	Timoshenko and Melan	Continuous redundant	Golden Gate Suspension Bridge
Energy	Hand calculation	1870–1980	Castigliano	Beams and arches	Sydney Harbour Bridge
Relaxation	Mechanical calculator	1932–1985	Hardy Cross	Rigidly-jointed frames	Empire State Building
Finite Elements	Digital computer	Since 1957	Argyris and Zienkiewicz	Stiffened shells etc.	Concorde/Sydney Opera House

Timoshenko [4] and Charlton [5].) Up to the 1960's educational methods needed to keep pace with analysis techniques so that engineers could perform the increasing range of analytical techniques and hence use them to gain insight into structural behaviour and to improve designs. When digital computers first became available, the pace of development took a leap forward with dilemmas for the engineering academics as to how to integrate these newer methodologies into curricula. It was rightfully claimed to be dangerous for students to be taught to use computer software without understanding the techniques on which they were based. However with increasing availability, reliability and user friendliness of software, it is now possible to question the need for students to understand the detail of the techniques employed.

There is a need for extensive debate about the objectives that should be adopted for civil and structural engineering courses and, leading on from that, the content and educational methods that are most appropriate. Since similar situations will be occurring in other branches of engineering, any debate on these topics should encompass different engineering disciplines.

PROBLEMS OF OVER-EMPHASIS ON SCIENCE-BASED LEARNING

> Civil engineering was as creative as sculpture or architecture, yet creative ability was stifled by too many lectures and too much formal instruction [6].

It is arguable that good engineering practice is rooted in:

- engineering principles based on scientific experiment and theoretical development;
- experience based on observation, study and criticism of past and existing works.

Although the building of structures must be one of the oldest engineering activities, there is little written information on analysis or design methodology before the 18th century. It may be inferred that knowledge was gained by experience with techniques being passed on by word of mouth within the profession of master builders. The extent of their mastery of the art can be judged by the legacy of medieval cathedrals constructed principally of masonry, a material unsuitable for carrying much load in tension (Fig. 2).

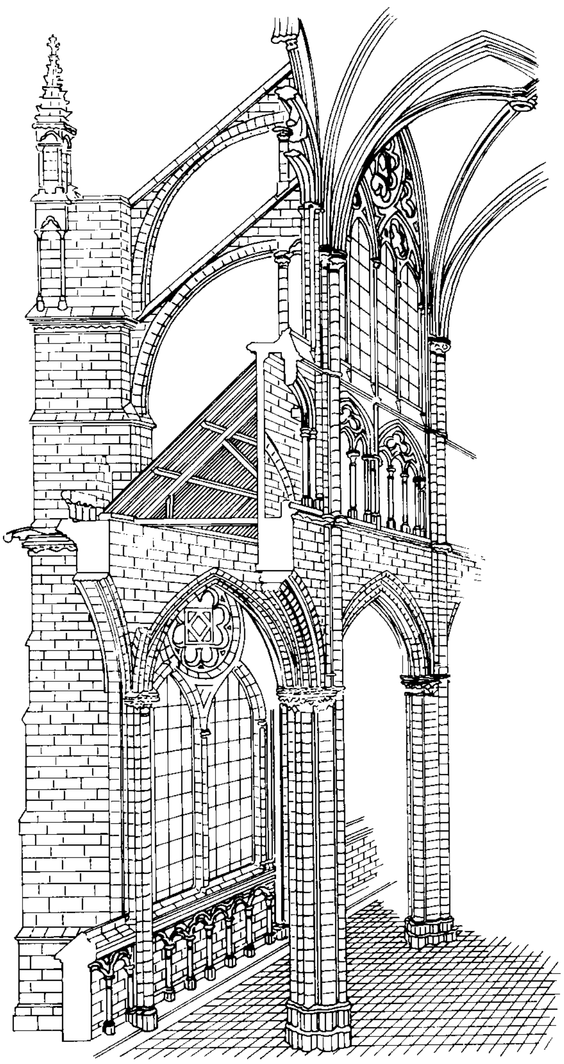

Fig. 2. The nave of Amiens cathedral.

The value of experiential learning, however, has not been emphasised in engineering education which has been mainly science based. Thus civil engineering students when graduating are definitely expected to know about and understand the equations of fluid flow and beam flexure, but are not generally required to have studied major historic engineering achievements or the engineers responsible for them.

Over concentration on scientific aspects in the education of engineers has almost certainly had detrimental effects on the development of imagination and innovation, business awareness and an understanding of social and environmental effects of engineering developments, all of which are important attributes of first class engineers. Too often engineers are facilitators of other people's ideas rather than formulators of policy. In the words of P. Rice they 'work behind a screen of other egos' [7].

In other disciplines such as architecture and law, education leans much more towards experiential learning than it does in engineering. Furthermore in architecture, this is seen as a fitting foundation stone for studio work involving design exercises. Since expertise in design is also a very important attribute for engineers, experiential learning should be given more emphasis in curricula.

To shift the emphasis in education so as to provide a better balance between scientific and experiential forms of learning requires much more than a rewrite of lecture notes. There needs to be a change in ethos affecting all aspects of engineering education. Thus:

- Prospective engineering students should be encouraged to study a broader spectrum of subjects.
- More textbooks are required which highlight experiential learning or which give a better balance between scientific and experiential forms of learning.
- Consideration needs to be given to the most appropriate forms of learning—despite financial pressures more individual and group activity involving open-ended assignments is desirable.
- Since engineering academics have mainly been appointed on account of prowess in science-based subjects and scientifically based research, priorities in appointing and training academic staff will need to be adjusted.

A FIRST STEP IN EXPERIENTIAL LEARNING

Good judgement is usually the result of experience. And experience is frequently the result of bad judgement [8].

Of all case studies, disasters provide the most positive and poignant lessons for the engineering profession. For that reason it was decided to organise an active learning assignment at Queen's University, Belfast (QUB) for Level 1 (1st year) civil engineering students, the first of which involved fourteen disasters and took place in January 1994 [9]. Students rarely know much about important disasters. When asked in advance about the fourteen disasters to be used, QUB students in Level 1 had heard an average of only three and graduating students knew of only five, two having been mentioned in lectures.

The exercise was included in a 'Communication Skills' module with objectives, not only of creating an awareness of some important disasters, but also of improving students' communication skills and their general appreciation of the civil engineering profession and how it operates [10]. An innovative aspect of the exercise was that the class of 96 was divided into groups of 6 or 7 with each group being asked to report on one disaster in one of two sessions. They were expected to cover:

- what happened and consequences;
- the technical factors contributing to the disaster;
- the human and managerial factors contributing to the disaster;
- lessons to be learnt.

In addition they were asked to take part in question and answer sessions, peer assess the other presentations in the same session and also write a short managerial report on a proforma. One of the important features was that the information being presented and discussed was what they themselves felt to be most relevant. Furthermore, they were able to identify how different factors may combine adversely and why constant vigilance is required. In this early stage in their studies, they did sometimes have difficulty in understanding all of the technicalities and aspects relating to work practices.

The second such exercise held in January 1995 differed by having less students who were able to be organised into fifteen groups of five with reporting in three sessions. In the first session groups 1–5 reported, groups 6–10 asked questions and groups 11–15 peer assessed their performances. In subsequent sessions these roles were cyclically rotated.

Table 2 shows the disasters used. Taking account of previous comments, groups were given greater encouragement and opportunity to seek explanations from staff and an honorary professor with lengthy industrial experience about technical matters and aspects of work practice. They were also advised to search the literature widely in order to find simple explanations of the main causes of the disasters.

One of the useful features of this exercise was the way it highlighted the very many different types of factors that can go wrong ranging from poor detail design (Hyatt Regency walkway) to what would now be considered as over-simplistic use of load factors (Ferrybridge cooling towers,) poor communication between consultants and contractors (Westgate bridge). Furthermore, disasters were seen to be particularly serious where inadequate provision had been made for the escape of people (which was the case for all the disasters presented in session 1). It also highlighted how structural failures are often sudden and catastrophic (such as

Table 2. List of disasters used in the 1995 exercise

Session 1	Session 2	Session 3
1. **Piper Alpha**, North Sea Fire on oil platform, 1988.	6. **Ronan Point**, London Progressive collapse in flats, 1968.	11. **Tay Bridge**, Scotland Collapse in wind, 1879.
2. **Hillsborough Stadium**, Sheffield Football crowd deaths, 1989.	7. **Hotel New World**, Singapore Complete collapse, 1986.	12. **Tacoma Narrows**, USA Wind vibration, 1940.
3. **Stardust Nightclub**, Dublin Fire, 1981.	8. **Aberfan**, South Wales Coal tip slide, 1966.	13. **Westgate Bridge**, Australia Box girder collapse, 1970.
4. **Herald of Free Enterprise & Estonia Ferry** capsizes, 1987 & 1994.	9. **Carsington Dam**, Derbyshire Embankment failure, 1984.	14. **Ferrybridge**, England Cooling tower collapse in wind, 1965.
5. **King's Cross**, London, Underground fire, 1988.	10. **Mexico City** Earthquake, 1985.	15. **Hyatt Regency Hotel**, Kansas City Overhead walkway collapse, 1981.

with the Hyatt Regency walkway and the Hotel New World).

It was noticeable that students did find technical and human or managerial reasons for all disasters. In the Hyatt Regency walkway collapse where poor structural design of a joint was the technical cause, it is relevant to ask about the managerial system which allowed an important detail such as that to be implemented without adequate checks. Also for the Herald of Free Enterprise, where there was a clear human failure to shut the bow door, it is possible to ask about the managerial system which allowed this to happen and the technical reason why ferries may become unstable when only a small amount of water enters the car deck. The availability of reports on the Herald of Free Enterprise, coupled with media reports on the Estonia ferry capsize made these two disasters a particularly appropriate topic.

A mock public inquiry is also run in the communication skills module. All Level 1 and 2 students take part in this exercise which, apart from developing communication skills, is intended to stimulate students' awareness of social and environmental factors concerning civil engineering works [11]. In January 1997 the Level 1 'Learning from Disasters' exercise was combined with a Level 2 study of hazards in which each Level 2 group reviewed a number of disasters within a specific hazard area and related these to current work practices. The ongoing plan is to run the disasters/hazards exercises and the mock public inquiry on alternate years so that every student entering Levels 1 and 2 in consecutive years will experience both types of exercise [12].

THE FUTURE TECHNOLOGICAL ENVIRONMENT

Focused intelligence, the ability to acquire and apply knowledge and know-how is the new source of wealth ... Of course, there is education—which becomes the crucial key to future wealth—but the key which takes a long time to shape and a long time to turn [13].

The increasing availability and use of computers and IT systems will continue to change work practices. Whereas engineers previously needed to spend much time on technical calculations, in the future computational techniques will be available to carry out tasks well beyond what is even now possible on the computer. Engineers will need to be conversant with the basic principles of the methods adopted including the assumptions, how to make idealisations and how to interpret results. They also need to be able to carry out appropriate checks. Although engineers will still be responsible for the accuracy of the analysis and design techniques, they will not do this by studying the intricacies of the computational methodology and programming but by insisting on well validated user-friendly software.

Most engineers will thus be spending more of their time involved with judgmental decisions which cannot be handed over to the computer. The structural engineer may, for instance, spend a great percentage of time examining special risks such as earthquakes, explosions or impacts of vehicles (lorries, ships or aircraft as appropriate) and considering fitness for purpose, ease of construction, minimising maintenance requirements, improving environmental impact, etc. Some other engineers, though, will need to specialise in the development of software for engineering, otherwise the computer programs developed by programmers are unlikely to reach a sufficient degree of suitability, reliability and user friendliness.

The expansion of databases together with general accessibility of these through the Internet will inevitably be exploited by engineers. One possibility is that information about past engineering works may be made available in a way which helps engineers to make the right judgmental decisions in any design study. No longer might it be sufficient to perform calculations following standard design procedures, but also it may be necessary to collect as much information of previous comparable projects as possible. If this includes not only design details, but also design parameters and decisions, and also information about the service life of the structure or artefact, then such information could be of definite value. In this way it may happen that new technology will give a boost to experiential learning instead of, as in the past, helping primarily science-based methods. By examining the timescales in Table 1 and speculating what major impetus may come next (see Fig. 3), it seems

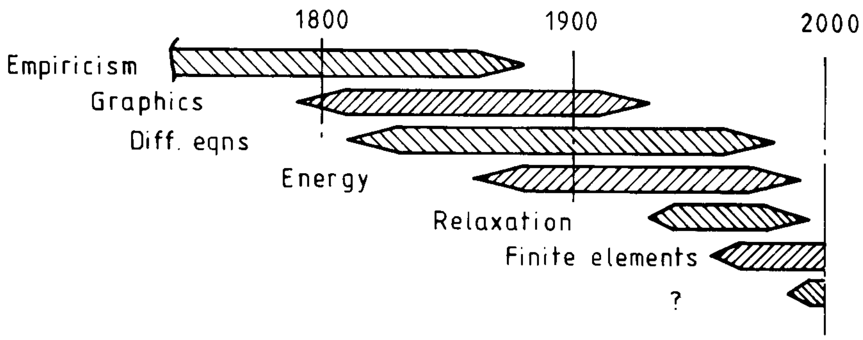

Fig. 3. Approximate timescales for major developments in structural analysis. What comes next?

possible that the use of IT to help with case study comparisons will provide the next ongoing phase of development into the twenty-first century.

CONCLUSION

In view of the changing technological scene and its likely effect on work practices, the time is particularly appropriate to increase the emphasis on experiential learning. From experience with a 'Learning from Disasters' exercise, it is possible to conclude that further developments in this direction, particularly where they involve student-centred exercises in a planned hierarchical structure, should correct problems that have been caused through over-emphasis on science-based learning through formal lectures.

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Alan Jennings is Professor Emeritus at the Queen's University of Belfast. He was employed in aircraft design for five years before taking up lecturing posts at Manchester University and, later, Queen's University, Belfast. He has been Head of the Civil Engineering Department and Director of Postgraduate Courses in Engineering Computation. He has also been a member of the University's Teaching and Learning Committee and is Chairman of the Northern Ireland Branch of the Institution of Structural Engineers. His research interests include computational methods for structural analysis and design and also the design of suspension structures. He has over 100 publications on these topics including a book on matrix computation which is now in its second edition. Interest in educational matters has grown for many years with the first publication in 1988.