The nature of civil engineering as a profession

W. F. CARMICHAEL

Dr Carmichael

It seems that in many of the qualities and skills required in civil engineering there are unique characteristics. Therefore we must examine occasionally our traditional values to see if they still carry the same authority. It is inevitable that some of these values will have been modified, so it will be prudent to attend to the implications of these changes.

54. One such modification occurs in the changed attitudes of both engineers and the public towards the privileges and duties of the professional. Some of the early professional ideals are for many engineers now largely untenable. The attitude of the public has also changed for there is now less deference towards professionals.

55. It does not necessarily follow, however, that our traditional skills in managing men and materials have lost their validity, although both, and particularly co-operation with and administration of people, have become more complex. Civil engineering is firmly based on theories, but engineering becomes an art when these abstract theories are translated to practical problems. For example, establishing what degree of accuracy is needed is a matter of judgement frequently assisted by statistical tools but in the last resort depending on subjective assessment and man management. It is right that we should have as much information as possible but T. S. Eliot's question, put in another context, should be asked: 'Where is the knowledge we have lost in information?'¹²

Mr K. G. Armstrong, Sir William Halcrow & Partners

Dr Carmichael's Paper has the measured serenity of the judge who can step back from the muddle and see it in a proper perspective. However, to step back to view the whole profession of civil engineering is not easily done. The orchestration of the theme that the engineer is steeped in the pragmatism of craftsmen and is disciplined by scientific rigour comes across very tunelessly, but I wonder whether it is not in a minor key. Is not the Author presenting civil engineering as a diminutive profession?

57. To illustrate this, in § 35 engineering economics comes in with the maxim that an engineer 'builds properly for £1 what anyone else can do, after a fashion, for £2.' But who has decided what is to be built? whether to or not? now or later? in this way or that?

58. In § 6 it is suggested that engineers prefer to leave most of the social and political decisions to representatives of the public. But how can these be separated from the engineer's commitment to do things for the 'use and convenience of man'? Can he safely delegate this responsibility and still remain accountable to society for his works?

59. The recent television series 'Where we live now' vividly depicted the disenchantment of people at large with tower blocks as suitable dwellings. Yet a prominent

contributor to the series asserted that modern architecture is now marvellous because of its systematic attention to functional design. When reminded that tower blocks had not been so acclaimed, he retorted that the architects were not to blame. There had been no sociologists to tell them what to do.

60. A fairly obvious moral is that if a profession is to depend on others telling it what to do, it must judge wisely in selecting their timely and relevant advice. An inescapable conclusion seems to be that the competent engineer must manage his public with all the sensitive care that he is ready to exercise on the physical environment.

61. Nowhere does the social role of the engineer become more potent than in the conceptual design of large and durable constructed works. These may last for many years, perhaps half a century or more. They may form elements of great infrastructural systems to be used by a society which seems to whirl through a vortex of technological advance and political upheaval at an ever-increasing pace. Can the engineer really leave decisions on these works to, say, uninformed members of a 3–5 year Parliament? How can he expect them to tell him sensibly what to do unless he can help them, first on when to consult him and then on how to go about their brief?

Mr D. Sparks

I am at present employed on the commercial side of a construction firm, having had a period with an overseas public works department.

63. 'Status' is the position of a man or his profession and his standing in the community, and it is something that has to be earned. There cannot be legislation giving the chartered engineer status. Current political manifestos of both parties show that neither wants civil engineers as a dynamic force in society. They want us purely as technical people, rather like plumbers to be called in when there is an emergency.

64. We often compare ourselves with doctors and lawyers, and we say that they have great status or that their profession is held in high esteem. They are rather lucky, because they see their patients and clients face to face. Doctors save people's lives and lawyers save their necks, and therefore when they are dealing with a client, that client is in a low emotional state, and anything the doctor or lawyer does for him fills the man with awe and great respect for that practitioner. Chartered civil engineers have no face-to-face contact with the public. The only time we ever come into the reckoning is when our structures fall down and we get blamed. The better we are, the less we are noticed and the less the public want to notice us. To take that to its logical conclusion we shall, in effect, become the faceless profession. Yet we are the only people responsible; the architects are not responsible for the infrastructure of society whether it is out in the bush in Africa or India or in Western civilizations. Why do we not court publicity? I think the answer is a very simple one, that civil engineering, like all chartered engineering, is something which is beautiful and clean. We do not have to deal with the dirt in society as do doctors and lawyers. We know at the end of the day that we have made progress, even though it may be negative progress. We can measure everything we do. Doctors, lawyers and clergymen cannot. We are more interested in our technical efficiency rather than in our effectiveness, and efficiency has been defined as doing things correctly, while effectiveness is giving attention to the right things.

65. Our Institution has by its latest rulings ensured that we have become more efficient, and some would say more academically efficient, without improving our effectiveness. To become more effective, we must obtain a greater knowledge of the support services which are required in construction. These include accountancy, commerce, economics, law, labour control, management, purchasing and quantity surveying. In all these professions, people are historians and recorders—that is all they do. We are losing a great deal of our power to the practitioners of these skills, and some of the practitioners are not even members of their own institutions. They strip the engineer of his power, leaving him alone with the gut-twisting responsibility for the technical and economic viability of his structure. When there is trouble on jobs, it is the chartered engineer who gets blamed. To have responsibility without power is

to court fiasco. Therefore, we must get back this power by encouraging selected members—all of our members I should say in the first place—to take a greater interest in what these other professions know and not just use them as advisers. We must even encourage suitable young civil engineers, financially and otherwise, to become commercial men, accountants or quantity surveyors, and strengthen the chartered engineering team within a construction firm, so that the chartered engineers will have complete control of that firm.

66. As regards the public, we must participate more in public affairs by becoming councillors and MPs, and entering into debates on television and radio, not just on our own subjects but on general subjects. Why do we have to leave it to the long-haired economists? Then, hopefully, when we reach a stage where people begin to realize what we do and that we are a force in the country, we shall get invited to be one of the columns in the corridors of power.

Mr C. D. W. Savage, Fellow

My first question is how would the Author propose to define a professional today?

68. Secondly, should there be any limit to the bounds of civil engineering? When it comes to evaluating a project it would seem to be important for the civil engineer to be prepared to turn his hand with professional thoroughness to many subjects outside the main stream of his work where it is nevertheless important for engineering judgement to be exercised. Earthquake risk is one such subject.

69. The need for this is exemplified by a proposal for use of wave energy on part of the fringing reef in Mauritius to produce low head hydroelectric power.¹³ The concept is elegant in its simplicity and environment impact is most probably negligible, yet in presentation it has been urged that the lagoon formed under the proposal would be ideal for fish-farming. As a coral reef, in its natural state, is one of the most potentially productive fishery resources known to science¹⁴ such a claim can only detract from the merits of an excellent project.

70. My third question is in regard to the civil engineer as an individual. I recently heard that an American firm of consultants was looking for a British firm which they could take over. This was in preference to building up a team to suit their particular needs. The reason given for this preference was that a firm was a group of people who were accustomed to working together and who knew each others' limitations.

71. Civil engineering has changed radically over the last 15–20 years. The science and practice of the profession is moreover developing so quickly in all its branches that it is difficult for individuals to keep up with developments. Over-specialization could destroy the role of the civil engineer as an implementor and co-ordinator unless the professional engineer is willing to develop his speciality as a member of a team while not losing his professional touch with bordering subjects in a much broader field. How does the Author see this?

Mr R. J. M. Sutherland, Harris & Sutherland

The Author has started so many interesting hares in this Paper that one could easily ramble. Perhaps I could take up one or two of his points.

73. He seems to think that appearance matters only if it shows (§ 44). I would like him to defend that attitude, because I believe that appearance in the broadest sense matters in everything. There is some need for every scheme to be elegant. It may be that the foundations looked elegantly economical before they were covered up or just that the mathematics were elegant. It is no good looking only at the final result. It may sound pretentious, but I do believe that with every piece of work we do, if we are to be truly professional, we should try to do a little bit better than the bloke next door. We should be proud to explain it afterwards and to demonstrate it. We cannot always achieve this, of course. I think that with modern design legislation we can be trammelled in such a way that we cannot pursue elegance sufficiently, and to that extent we

are losing out on our professionalism. With the current restrictions, there is often more scope for creativity in designing temporary works for permanent works than in designing the permanent works.

74. I agree with the Author about craftsmanship and that design often involves bypassing problems rather than going at them head on. It is when he talks of scale demonstrating originality (§ 40) that I do not understand what he means. It seems to me that originality has nothing whatever to do with scale. For instance, the Verrazano-Narrows Bridge is in no way original, but it is very big: the Severn Bridge, which is almost exactly the same age, is extremely original and is much smaller.

75. On the question of education, I think that an inquiring mind is needed rather than knowledge. I would ask the Author whether he does not think that present day technical education is concentrated too much on providing the knowledge. How does one persuade students to have ideas, to see a bit beyond their profession and to take on more responsibilities than they have to? If the Author can achieve that, I think he is achieving a great deal.

Dr D. E. Wright, Sir William Halcrow & Partners and Halcrow-Balfour Ltd

It is very good that from time to time we should have stimulating papers of this kind before us to enable us to stand back and to take a look at what we are, what we are meant to be and where we are meant to be going.

77. The first point I want to question is whether engineering is simply the application of science. In § 12 the Author appears to present the classical view that scientists make the real advances in knowledge and understanding, and that all the engineer has to do is to apply them. In § 26 the Author slightly changes his stance by acknowledging that the great engineers of the last century extended concepts beyond what was strictly understood and the credible limits of then known theory. Mr H. G. Edmonds, then of the University of Exeter, wrote on this matter as follows:¹⁵

'... there is a substantial error in the common view which is often expressed in a diagram which shows the amount of knowledge that exists over a spectrum of topics into which the whole of science is considered to be divided. Research is shown as brave little arrows thrusting out from the explored zone of established science into the great unknown, whilst technology is shown as a laggard discipline whose activities are wholly contained in and lag well behind the limits of established science. Applied research is seen as a sort of evangelical activity which has the function of leading technology forward in the light that science has cast, but in mechanical engineering at least I believe the truth is very far different. There are two factors which have made it so. One is the lack of adequate research in the areas of more immediate importance to engineers, and the other is the great pace of technical advance that has been experienced over, say, the last twenty years... The result is that in many areas technology has gone thrusting far beyond the confines that would be dictated by rational science, with the further result that applied science has been left floundering in the no-man's-land between science and technology, trying to erect from the firm ground of science some sort of scaffolding that will support the technological edifice. In such a situation it is all too evident that the engineer is thrown more and more upon the need for technical judgment... Advance in engineering inevitably means extrapolation from past experience, but when that extrapolation must remain outside the bounds of established science it becomes doubly clear that a vital faculty of an engineer is the ability to ask questions about the novel situations to which his designs give rise...'

Although the author was writing from a mechanical engineering background his remarks apply equally to civil engineering. With the advent of team involvement in large projects, the opportunity for 'heroic' design by one engineer does not now occur, yet the concepts being developed by the engineering team may well be ahead of established engineering science.

78. My second point links with the need to ask questions. In § 17 the Author says that engineers would prefer to proceed along traditional well known paths rather than try new methods. In §§ 18 and 19 he remarks that independence of mind is an absolute ingredient (in passing giving a side swipe at codes) and comes to the crunch in §§ 27 and 29 where he writes that 'the engineer must judge which external conditions and internal behaviour will be most damaging to his proposals' and then, 'Thus imagination is needed, imagination which must be extremely accurate, numerate, and practical, and tempered by economy and directness of function . . .' I think that this may be one of the most important things that Dr Carmichael has put in his Paper. Without a technically inspired imagination which is able to project him into a position where he can foresee different combinations of circumstances, the engineer is in a very dangerous position. A question not posed is a question not answered, and a question not answered, I believe, can represent a dangerous risk.

79. I shall never forget seeing literally half a 200 ft high dam: on first filling, the other half had been washed away. The engineering knowledge needed to prevent this horrific accident was commonly available, but the people responsible for construction had not put themselves imaginatively into the position to which their actions were leading and from which, in fact, they had finally no escape.

80. Can engineers be taught to exercise this sort of technical imagination? I think that some of the qualities required are inborn. One can teach a certain amount of knowledge, and one can encourage the asking of questions, but that roundness of view which enables one on the basis of existing knowledge to foresee situations which could occur is, perhaps, the mark of the truly great engineer.

81. In my third point I ask about the place of design in university education. In § 46, the Author speaks of the design process as an amalgam of the pragmatic and the theoretical, and in §§ 47 and 48 he discusses the place of design in education.

82. I believe that an engineering course is not an engineering course at all unless it at least starts to transmit an appreciation of the essence of engineering activity, namely the creative and responsible application of knowledge for practical purposes.¹⁶ In a word, an engineering course must at some stage be involved with 'design', which, with the Author, I consider to have the ingredients of utility, safety, economy and beauty.

83. At Imperial College in the late 1960s we used to try to show students that as well as requiring co-ordination of different areas of knowledge, judgement and the ability to decide, design was a semi-logical and sequential/iterative process involving, for example, the identification of need, preparation of possible solutions, recognition of the questions each posed and selection of the solution preferred.

84. I would warmly support the Author's plea that design should be part of every engineering course, even if it is done only in a fairly small way, and I would like to know what is done at Heriot Watt University. Two ways of including design in undergraduate courses are through 'properly framed' design projects and the description of case histories of major projects.

85. I am grateful to Dr Carmichael for this opportunity to reconsider some of the foundations on which our profession is based and I agree with much of what he has written. Are we being hopelessly idealistic? Are the concepts of civil engineering as a profession which are presented way out of touch with ordinary everyday life in the design office or on site? Perhaps in some cases they are, but if we are never to look ahead and dream dreams, and to recall what civil engineering basically is all about, we shall be very much the poorer.

86. At the beginning of his Paper Dr Carmichael says that the professional regards service to his client to be beyond the aim merely of making money, and that if the professional is to be trusted by society, values as well as competent skills have to be displayed. I think the extent to which we can put this into practice depends on our own personal professional integrity, and on our view of what civil engineering should be, not simply on what may appear to be achievable on a day-to-day basis.

87. Although the services of a professional can be hired, his opinion can never be bought.

Mr D. A. Cook, University of Bath

I find in Dr Carmichael's Paper a very comprehensive statement of the present day nature, ideals and problems of the civil engineering profession. It is a timely document at the present period when the profession and its method of working are the subject of public scrutiny.

89. I was impressed by the choice of structures used to illustrate the theme. It is a reflection of modern day working that structural engineers and architects can also enjoy some reflected glory from the examples given, and I should not think Dr Carmichael means to differentiate in any way between the two fields of engineering, if not architecture as well.

90. The position of an engineer faced with social and political pressures is indeed a difficult one. The Paper offers no specific solutions here, which is understandable. The emotional content usually renders them intractable. People adopt the benefits of engineering achievement and new technology with hardly a murmur, while reacting quite violently to the shortcomings. Such criticism, however, is one stimulus to progress as well as a safeguard against the purely commercial approach to engineering functions, particularly in production. It is what we choose to call democracy.

91. In this context, Dr Carmichael mentions the possible conflict of conscience (§ 5) for a professional engineer in a commercial firm who finds himself custodian of trade secrets. I should not expect any serious dispute that the engineer must remain loyal to his employer. The overall benefits that accrue to the construction process through an intermix of engineers between contractors and consultants have been seen to outweigh the disadvantages, and general agreement to this point would appear to come from § 38 in the Paper. By contrast, architects have rigorously maintained a separation from contracting and commercial organizations. I think architects have sacrificed technical competence as a result and the building industry has been starved of a valuable source of management personnel.

92. The Paper deals only briefly with aspects of education, so the implications of the Author's specification for a civil engineer are left open. Professor Coates' Presidential Address, also published in the February 1979 issue of *Proceedings*, provides an excellent review of this topic. His introductory remark '... Educational topics at any level can cause violent controversy, a frictional interaction normally producing heat without illumination ...' is fully understood by all teachers. Dare I ask if this influenced the Author's wish to express himself more fully as an academic in his own right?

93. Nevertheless, indirectly or specifically both papers infer the need for more than pure technical expertise, and politics, sociology, language and project work are included among the needs. This brings me back to my earlier remark concerning the illustrations used in the text. Much of their merit devolves from the total integration of all aspects of the design. Engineers who can completely master all the necessary skills are very rare, while the structures they have to build become more complex. Design and construction tends therefore to be the product of a multidisciplinary team effort and it is the success or failure in that sphere which reflects in the finished article.

94. At the University of Bath this problem has been approached through an integration of the undergraduate courses in architecture and building engineering for the first two years of the four-year curriculum. From this common foundation, undergraduates will complete the course, to CEI standard or the RIBA Part I. After two years' studies they still have the option as to whether they elect engineering or architecture, or neither. Whatever their choice the ultimate civil/structural engineer, the building services engineer or the architect will have an understanding of the disciplines he must collaborate with as well as understanding his own. An integration process of this nature is not without its problems and it is an investment for which it will take several years to see a pay-off.

Mr P. H. D. Hancock, George Wimpey

This Paper is full of ideas. For instance, on innovation in design, the Author talks about independence of judgement (§ 18); about the engineer's peers, fellow engineers, as being the third client (§ 28); and about imagination to foresee a new concept (§ 29), and to see how it might fall down. If one went through the Paper one could probably find a whole set of ideas which add up to the conditions for the successful conclusion of design, and the obstacles to it.

96. What worries me about modern design is not only the codes, but the tremendous penalties of failure compared with the small rewards for a design that is anything more than pedestrian. About the same time as Brunel was designing and constructing that fantastic Saltash Bridge, he built an atmospheric railway which was a complete disaster and nowadays would be in the press for years as an example of the total incompetence of engineers. But then people were dazzled instead by the *Great Eastern* or some other engineering wonder. The climate has changed.

97. The question of status (§§ 10–12) is a complicated problem. I think it is now becoming recognized that science (i.e., unapplied knowledge) has greater standing than useful knowledge. The general public still does not understand the difference between science and engineering. It will be at least 5–10 years before we have an Engineering Research Council. We have science and engineering advisers now in the Department of Industry, and in five years it will be the Science and Engineering Research Council, and then in ten years perhaps it will be the Engineering (Science) Research Council!

98. It is obvious really, but it is nice to see it said (§§ 7 and 8) that anybody making design decisions is working in the value climate of his age; one of the advantages that 19th century engineers had over us is that they were inheritors of the classical tradition of design. People could give Brunel high marks for designing Maidenhead Viaduct without any architect, but he was working at the end of an artistic era when everybody knew what was right; whereas nowadays none of us knows what is right, aesthetically or in any other way. If we recognize that our design decisions are not value-free, that is a start.

99. On the question of linking design and construction more closely (§ 38), I think that what really took me away from consulting engineering into contracting was the interest and excitement involved in the design of temporary works. It is so often far more rewarding than doing drawings and erecting a huge barrier of bills of quantities and contract documents between oneself and the person who will be carrying out the work.

Mr I. T. Millar, Property Services Agency

I suppose if you put a bottle on a wall, somebody will throw a brick at it sooner or later, and I feel that this is the situation with codes. My personal definition of professionalism is that it combines duty to the client with duty to the public at large. Increasingly, because of a failure towards the public at large, the public is defending itself by legislation. I have a feeling that this situation has arrived because we have not supported our own professional codes strongly enough. It may be that if adequate codes of practice had been followed, much of the legislation that is now weighing on us would not have been necessary. I hope that the Author in his reply will discuss the position of codes of practice and professionalism.

The Chairman, Mr R. W. Horner, Greater London Council

I was very interested in this idea of status, and I do agree that status has to be earned. Status means that people respect you, they hold you in high esteem: this cannot come because you belong to the Institution of Civil Engineers, or because you have taken a certain course of study; it must depend on your own qualities and abilities. We are told that doctors and lawyers have status. I am not so sure. I remember an old farmer who had the highest contempt for doctors, saying that if he had a rather stupid son, the

DISCUSSION

obvious thing would be to put him in to be a doctor; if he had a good practice and followed the rules, he would not come to any harm. As to lawyers, a lot of people think they are a crowd of twisters! So I would not place too much emphasis on a profession having status.

102. We perhaps bemoan the change since the time of Brunel, when the engineer on the job stood very much on his own, and everything revolved round him. Now with the widening scope of technology there are hosts of specialists, and the man who runs the team has to understand the specializations. This does not mean he has to have a comprehensive knowledge in them. The people who are in the role of client, whether they represent government or local authority or act as individuals, want to have a single individual they can talk to and hold responsible for the results. I think this is a human quality. I do not see how it can be otherwise. You cannot pin responsibility on a committee. If you go along with the idea that one man has to lead the team, then he must know the part and place of every member of the team. But also the idea of a team suggests that all are equal within the team. They have different roles to play, but being members of the team they are equal, and I am not happy about the division of people into professional and technical categories within our own profession. Within a team it does not seem to me there is room for some people to say that they are professional, and therefore higher members of the team. Every member of the team is necessary and plays his part, and there is a sense of equality throughout. The man who is leading the team needs to understand what is going on, and when something goes wrong, he should be able to admit it and give the reasons. Today there is a lack of this quality. People are not willing to take decisions. They refer the matter to some committee or another group, or bring in some expert, and when things go wrong they say that they have followed the advice given to them but it did not work. But the man who is the leader of the team is responsible for the individual to whom he goes for advice. This is rather strong medicine, but if people want to earn status and esteem, these are the standards they have to live up to.

Mr Hancock

As a practitioner I have had the misfortune on more than one occasion to be part of a team which has had to meet the client, and when we went to meet the client, it was barely possible for us to get into the same room because the 'client' consisted of 30 people! It was a very large and bureaucratic organization, and in such organizations there is always a tendency to diffuse responsibility.

Mr R. M. Ashley, Thames Polytechnic

The civil engineering profession is unique in its potential role in the socio-technological-constructional field, in that it is the link between the sciences and construction (Fig. 19). The interface with society for civil engineering is different from that for mechanical or electrical engineering as it is never concerned with consumer goods but always with the human environment. In this sense it is the mathematical expression of architecture. The awareness of the fact that the civil engineer is potentially in the fundamental position as contributor to the quality of the human environment may only be achieved if it is recognized by the profession as a whole, and if the civil engineer wants to accept the role.

105. If the above contention concerning the relationship between architecture and civil engineering is acceptable then the current diversity in attitudes and education must be reconciled. This diversity evolves from civil engineering training being based on university science courses, and architecture developing more from the arts disciplines. Certainly in terms of the construction industry the training of civil engineers can benefit from the influence of the longer project-orientated architecture courses.

106. Most engineers work in an employee role, in many cases virtually as technicians, and as such their designation 'professional' is difficult to employ. Within the engineering professions as a whole the difference between the 'principals' and 'em-

ployees' is very important and when discussing the role of the professional this difference should be carefully considered. The difficulty of attempting to serve the needs of the two classes of members is a crucial problem for an Institution when establishing policies. The average 'employee professional' is now far removed from society, as most civil engineering works are of a large-scale nature and worked on by teams of engineers, each concerned with a small part of the whole. Local authority work, however, is often the exception to this, particularly local traffic schemes. In such cases the engineers are involved much more closely with the public and are often embarking, for this age, in a 'new' aspect of civil engineering for which they have received no training, or indeed no definitive corporate civil engineering advice. Successful interaction with the public has been achieved despite this, notably in Lewisham,¹⁷ where public participation rather than just consultation has been achieved. Such approaches are unfortunately often beyond the province of the average civil engineer who serves one part in the work of a team of professionals. Even the interaction with other professionals is badly neglected in engineering education and training, often only those graduates working on structural engineering designs having the opportunity to meet architects. This is too late in the education process anyway, as attitudes are normally formed before then, as Dr Carmichael points out.

107. The remoteness of the average engineer from society makes the distinction between the 'immediate' and the 'larger' client difficult for him to discern, particularly as education and training provide little guidance as to the needs of the society as a whole. Other professionals are developing expertise in this area; for example, planners and landscape architects, and their concern with environmental impact analysis (EIA) techniques.¹⁸ Certainly within the Institution of Civil Engineers there has been little discussion as to the relevance and application of EIA techniques to civil engineering works. In marked contrast, the American Society of Civil Engineers is having a lively on-going discussion of EIA applied to civil engineering works in the Engineering Issues Journal.

108. The abysmal record of engineers in the UK compared to their European counterparts in reaching senior management positions alongside other professionals is

Fig. 19. Input to and output from civil engineering

DISCUSSION

best explained by the contrast in their education and training. The academic life of three years, or thereabouts, of intense, only remotely applied work, results in a narrowness of outlook which cannot be adequately repaired by the following three or four years in industry prior to qualification. Unfortunately government and market pressures are tending to exaggerate this phenomenon by requiring a quick return from any investment in education. Equally, students want a training for a job, rather than an education for a complete view of their profession, which will only apparently be of use to them at some time in the remote future and only if they succeed in becoming real professionals. This attitude of course stifles any possibility of originality of approach in education and subsequently design as called for by Dr Carmichael. This, and 'openness' in developing a final design, require longer degree courses committed to providing an education rather than training.

109. The unique role of engineering in society was recognized formally by the Nuffield Foundation¹⁹ as long ago as 1974 when money was provided to sponsor undergraduate engineering projects of a socio-technical nature (General Education in Engineering: GEE). This sponsorship has continued in the form of Socio Technical Engineering Projects (SOTEP) but unfortunately very few civil engineering departments in higher education are involved. The most significant contribution comes from electrical engineering departments, notably at Imperial College via Dr Sinclair Goodlad. This socio-technical programme has been termed 'The engineer really in society'.

110. The personal view of individual responsibility of the civil engineer can best be developed via project work in civil engineering degree courses. This must involve close association with other professionals at an early stage, and the development of interdisciplinary projects. Guidance and assistance in achieving this has arisen from the GEE group via project manuals (e.g., Cotgrove²⁰) and seminars for tutors.

111. To create a professional image and to actually take up the reins of environmental and social responsibility requires a different attitude from that of the average engineer which must be instilled at an early stage in the development of his career. It must be inculcated by the education process initially. This education would not be in the form of an increased depth of academic attainment, but a broadening into a real education rather than the pressurized 'training' that exists in the UK at present, and the development of courses to discover the 'whether' and the 'why' of engineering problems rather than just the traditional 'how'. The present vague 'Engineer in society' topic must be tackled in a meaningful way by the setting of real projects early in the education process in which the engineer has to work within a multiprofessional design team.

Mr A. W. Shilston, Consulting Engineer

I would like to complement the source material which the Author has provided to assist present and future members of the Institution to reach personal conclusions about the true nature of their professional function and role. As the Author so clearly demonstrates, it is a difficult task.

113. The Institution's royal charters, by-laws, regulations and rules are not sufficient in themselves to set the entire reference background and starting position for any investigation and discussion on the true nature of professionalism. One ought to proceed from any statute law requirements and the decided cases. This contribution should be viewed in the light of the position in England and Wales, as it may be that the Author's mental processes have been conditioned by Scottish Roman Dutch legal precepts rather than the common law inheritance pervading England and Wales. There perhaps could be distinguishing features in this particular discussion context.

114. From the very rare judicial discussion on this subject, useful guidelines as to the view the Court takes on the professional function are to be found in the reports on proceedings which started in the Chancery Division of the High Court in 1966 and duly ended in the House of Lords on a restraint of trade issue pursued against one of its

members by The Pharmaceutical Society of Great Britain, incorporated by royal charter in 1843, regarding the duality of the 'professional' and trading activities conducted by many of its members. The following extracts from the decisions of the High Court, Court of Appeal and House of Lords are thought to provide a distillate of the prevailing general position at law regarding 'professionalism' in the true and not the colloquial sense with which that word is frequently used.

*Pennycuik J, Chancery Division, High Court, 1966*²¹

'It is clear from . . . statements of high authority that a restraint of trade is to be regarded as contrary to public policy unless it is reasonable in each of two respects, namely, the interest of the parties and the interests of the public . . .

' . . . Counsel did not, however, as I understood him contend that rules of conduct laid down by professional bodies are, by their very nature, outside the scope of the principle of restraint of trade. This is, I think, clearly not so.'

*Sachs LJ, Court of Appeal, 1967*²²

'A royal charter cannot of itself justify a restraint—at any rate where there is no antecedent custom, and the mere fact that the restraint is imposed pursuant to the objects of such a charter likewise cannot justify it.'

*Lord Upjohn, House of Lords, 1968*²³

'I am entirely unable to accept the argument that professional bodies are outside the general doctrine of restraint of trade.

' . . . These judgements (cited previous decisions) establish that there is no exception in favour of a profession from the general rule that the doctrine of restraint of trade applies quite generally.

'The reason why this doctrine as affecting involuntary restraints has not been applied to a profession in any reported case is, to my mind, clear. It is not because it is exempt from this doctrine at all. It is because in applying the doctrine to a profession there is this additional relevant circumstance to be considered. A profession is a vocation of the highest standing; it calls on its members to serve (no doubt for reward) the public by offering to them highly technical and always confidential advice and services, which require a different standing of conduct from the tradesman. Its members stand in a different relationship altogether from the man doing ordinary business. So much so that in many cases they are presumed to exert an undue influence on the client.

'The professional code, however, must be different by the nature of its calling and the reliance placed on it by the public from those carrying on trade and commerce. . . . The restraints on professional men are justifiable in law for they are necessary not only in the interests of the profession but also in the interests of the public, who trust to the peculiarly high standing and integrity of a profession to serve it well.'

115. All truly professional activities involve restraints of trade but these are justifiable in the eyes of the law where reasonable in the interests of the parties *and the interests of the public*. A primary rule of our own Institution's rules for professional conduct, stating that

'A member, in his responsibility to his Employer (or Client) and to the profession, shall have full regard to the public interest, particularly in matters of health and safety',

is clearly supportable in law. Within the requirement of reasonableness, the duty to have regard to the public interest should be visualized, accordingly, as seated in law rather than in the nature of 'egoistic indulgence' (§ 5 of the Paper).

116. The Author (§ 50) considers that 'The engineer's position is somewhat similar to that of an advocate (barrister)' and that 'One of the problems facing the engineer is to decide whether the legal or the medical conception of a professional best suits civil engineering'.

DISCUSSION

117. By reason of the existence of an unwritten code, the advocate's duty to the court ultimately transcends the duty owed to the client. The barrister, thereby, has a compelling duty in custom to have regard to the public interest. In this particular respect, with the sanctions imposed on failure to observe this superior unwritten duty, no other profession has such demanding external obligations imposed on it beyond the duty owed to the client or employer. However, beyond the broad public interest common feature, it is difficult to identify in what respects the civil engineer's professional position is analogous with that of the barrister.

118. The adversarial role of the barrister in court, with the strict prohibition on any attempt to express his own personal views, the absence of any professional duty to question and test independently the validity of the material supporting his brief or instructions, and the traditional position taken of remoteness from and uninvolvedness with the client, all point the other way. Quoting Diplock, in a 1968 judgement in the Court of Appeal:²⁴

'The professional duty of a lawyer is to express the views of his client, not his own personal views. That is one of the reasons why lawyers, as a class, have through the centuries been distrusted by laymen.'

119. A medical practitioner on first seeing a patient and therefore in quest of evidence would listen to what the patient had to say but would reach no conclusions until he had carried out his own independent inquiries and tests. He would not act solely on the patient's observations and requirements. A professional civil engineer acting in an advisory capacity surely should adopt a similar approach on receiving initial instructions.

120. Each chartered civil engineer should adjust his professional frame of reference to the circumstances of his instant engagement in the light of the requirements of law in the situation of that engagement; the basic tenets of the profession as exemplified by the charters, by-laws, regulations and rules; the periodical utterances of the Council; and the study of all-too-rare published literature, such as the Author's valuable Paper, to afford scope for reflection and guidance in setting that frame.

Mr D. W. Smith, University of Dundee

Though Dr Carmichael's Paper makes very interesting reading, it can hardly be claimed to be a balanced or thorough-going discussion of the nature of civil engineering as a profession. In these days when much of what was called civil engineering in the 19th century is now normally excluded from that title, and when more and more of us are being urged to join trades unions, and even to withdraw our labour on occasion in order to demand higher wages, we are very much in need of a new definition of civil engineering, and also of a profession.

122. Civil engineers are more often called on to fight, rather than to direct, the great sources of power in nature. Wind, earthquake, tide, waves and even gravity are more often tigers to be caged rather than horses to be harnessed. The people who harness the forces of nature are now, for the most part, mechanical and electrical engineers, and the definition of civil engineering should be rewritten accordingly.

123. A professional person is someone who does his utmost for his client in return for his fee. Professionalism is therefore altogether incompatible with militant trade-unionism. The Institution of Civil Engineers will have to take a much more positive stand in this regard if it intends civil engineering to continue to exist as a profession in any recognizable sense.

Dr J. Cowan, Heriot Watt University

There will be many readers of this Paper who will warm to the suggestion made in it that the profession of engineering is now very much an alliance between the scientist and the pragmatic craftsman. While I do not disagree with this statement, I think it might be helpful if it could be amplified. Would Dr Carmichael give a definition of the

term 'craftsman' as he is using it in this context, and would he expand on the relevance of such craftsmanship in the present day situation?

Dr Carmichael

I agree with **Mr Armstrong** that it is difficult to view the whole of the profession of civil engineering, but the discussion contributions in general indicate that it can be worthwhile. In such a relatively short paper, the elements will only be sketched—sufficiently for **Mr Sutherland's** hares to be pursued and perhaps provide sustenance for the engineers.

126. **Mr Armstrong** suggests that the summary presents civil engineering as a diminutive profession. In order to answer that, I would like to link it with **Dr Cowan's** question on the definition of a craftsman and **Dr Wright's** question about engineering application being simply applying scientific formulae. Part of my thesis is that civil engineering at its best is an alliance between the craftsman's approach and the scientific approach. This is necessary in order to resolve the radical difference between the subjective personal activity of the creative engineer, the objective impersonal knowledge of scientific principles and the heterogeneous qualities of the engineering materials. It is impossible to be certain that a theory is perfectly relevant to the behaviour of the particular situation. An important element in using a scientific model to analyse a design is to have the craftsmanship to know which data is relevant—how to evaluate the information—to be sensitive to clues which indicate the presence of pitfalls as well as unique possibilities. Freyssinet is an example of an engineer who has developed such a craftsman's sense of the powers and limitations of applying scientific principles to specific problems. The difference between a mathematician and an engineer is that the engineer uses his mathematics pragmatically after a certain stage and is not rigorous throughout all the stages.

127. A question that must arise is whether a pragmatic approach is necessary because of our present state of knowledge or whether it is intrinsic to civil engineering. It is argued here that it is intrinsic, because the craft characteristics start when abstract principles are related to the external world of men and materials. If blunders are to be avoided, if excellence is to be achieved, it will be because engineers develop these craft characteristics. The solution of an engineering problem involves personal choices as well as personal judgement, partly derived from the engineer's own experience, partly from colleagues and teachers, and partly from his own unique set of interests, skills and preferences. No two engineers can set and solve exactly the same problem unless it is one which is routine and straightforward or is a conventional exam question. The circumstances of the problem are often malleable, and therefore conclusions can vary in emphasis and in form.

128. In addition to these characteristics, the kind of craftsmanship mentioned in the Paper treats a problem as a whole, and knows best how to form material for whatever use is made of it, so that it stands up to that use and to the destructive elements. Such a craftsman knows how well the materials fit together, knows how best to select, adapt and extend existing engineering systems while still ensuring safety, function, economy and practicability, but still retains a grasp of principles, not rules of thumb. It is essential that this definition of craftsmanship includes the skill of working with people and embraces a joy in engineering. **Mr Hancock** makes a good point when he speaks about the 'excitement' involved. This kind of craftsmanship with its strong base in scientific principles will not produce achievements in a minor key—as **Mr Armstrong** suggests my description implies—but will stand comparison with anything in other fields.

129. These qualities when allied with scientific theories and attitudes are the tools of civil engineering. The answers to **Mr Savage's** question on the limits of civil engineering will depend on the use engineers can make of these tools for the material and social benefit of the public and the immediate clients. **Mr Savage's** contribution indicates the wide range of possibilities. A more detailed answer would mean a too rigid and restraining definition for this period of inevitable change.

DISCUSSION

130. These tools, however, are not only for the technical feasibility of the engineering solution but also for achieving economic feasibility. It is the engineering function, as compared with the scientific, to bring together resources so that a product giving practical and social benefit can be made at a reasonable cost. In many cases the economics of the solution will be the governing factor—not so in science. Recognizing this fundamental difference does not make engineering 'diminutive' in comparison with science.

131. The efficient, and therefore economic, use of these tools with the kind of social responsibility mentioned in the Paper is part of the definition of the professional. Whether the engineer when he is an employee is now able, or wishes, to take that responsibility is one of the questions posed by the Paper and by Mr Ashley. The answer will not be given unilaterally by a professional group; the public will also take part in forming the definition, especially if claims for a monopoly of work, control over entrants or particular financial arrangements are demanded by the specialist group (demands, incidentally, which are not far removed from some aspects of modern trade unionism). Mr Shilston's informative contribution indicates a groundswell of legal and public opinion against any unilateral claims by professional groups.

132. The cultivation of the trust of the public, a necessity for any profession if it is to remain professional, and not to change like the ancient craft guildry or masonic societies, is a continuing operation. How difficult it is has been noted by several contributors.

133. The contributions from Mr Armstrong, Mr Savage, Mr Cook, Mr Sutherland and Mr Ashley highlight the difficulties of the professional engineer when faced with the social and political phases of decisions to construct an engineering product, especially when there is a conflict between the public and the client. The public participation in these decisions brings a challenge to the professional engineer: how, for example, to deal with a pressure group opposing the views of the elected representatives. Both parties claim to represent the public good, the assumed view of the silent majority, present and future. The advice which the professional must give must be satisfactory to this silent majority. Mr Armstrong's question about forming the brief in the face of 'uninformed members of a 3–5 year Parliament' shows some of the dangers for both sides. The Skeffington report, *People and planning*,²⁵ examines this problem. The Chilver report²⁶ says: 'a breadth of outlook will enable the engineer to be mindful of and guided by the social consequences for which he will also accept his share of responsibility'. But the engineer must be careful not to accept some areas of responsibility which belong to the public.

134. The engineer should arrange that the client is aware of the relevant choices, and recognizes what the client is responsible for deciding and what the engineer is responsible for deciding. Perhaps in some cases engineers are unconsciously making some of their own choices, and sometimes even withdrawing from taking their professional part in the making of initial decisions. It may be, as Mr Ashley suggests, that the 'average employee professional is far removed from society', but value judgements are made at all levels.

135. Mr Shilston takes issue about my suggestion that engineers will have to choose, if they wish to be professional, between the medical and the legal concepts of a professional. My opinion is that at the extreme of the legal concept is the view that the advocate will do what the client would have done if only he had the necessary expertise, subject only to laws of the country. Thus, with advocacy, the criterion depends not on justice but on the law. The medical concept, as with accountancy, has the professional interposing between the client and the general good; as, for example, in abortion, child battering, research, or even when certifying the ability of a disabled person to drive a car or return to work. These two kinds of concept of professionalism were used as examples in an attempt to show the choice that has to be made, but others may regard modern professionalism as simply being a member of a learned society with tribal characteristics giving status.

136. Mr Millar's perceptive question about the relationship between use of codes

of practice and professionalism highlights the changing pressures on the professionalism of the civil engineer. To be capable, whether as a professional or not, means, in my view, taking on the entire responsibility for one's own opinions, decisions and actions, as **Mr Horner** so succinctly says. An engineer uses codes as he would textbooks; that is, as a basis for competence and as a starting point for achieving excellence. In these urgent days it is plainly impossible, apart from undertaking a new type project, to base every scheme only on facts which the engineer has verified himself. It is right that we should have as much information as possible but I agree with **Dr Wright**—engineering is not amassing information and applying a formula. The designer of a coffer-dam requires more than this when he has to decide between providing for adverse floods at a high cost or taking a risk that a catastrophic flood will not occur during the short life of the coffer-dam. He has, moreover, to face the consequences of that judgement. While use of the codes can produce competence for a substantial part of engineering—a valuable and indispensable requirement—it cannot guarantee competence for all aspects, nor can it automatically produce excellence. These achievements will require personal judgement, skills and preferences, springing from a strong base of codes, textbooks, experiments and experiences. The developing engineer should understand that the totality of engineering is beyond codes of practice.

137. The view appears to be taken that codes are a combined responsibility of the profession and government, but institutions are reluctant to pronounce on specific applications of a code. The law courts take over that duty, even if the profession of law itself deals with breaches of its own code. Experience has taught the public not to expect retribution from engineering professional institutions, and inevitably this erodes the general corporate responsibility but means that the individual responsibility of the professional is greater and allows the public to have a voice. It also means that the dividing line between commercial practice and professionalism is blurred.

138. Information by itself will not help the engineer when he considers appearance. **Mr Sutherland** queries the opinion that visual appearance for a product which is not to be seen is not thought of as a prime necessity by a substantial number of engineers. I do not defend that attitude: the Paper (§ 45) also cites the opposing view of Freyssinet and Mailart. Perhaps the essence of **Mr Sutherland's** criticism is that every artifact needs to have elegance and thus that the result should indicate the excellence of the process of thought. This is so, but I draw a distinction between elegance, which is a particular kind of beauty and is largely derived from a disciplined logic, and visual appearance, which can be derived from logic but can have other derivations.

139. Another of **Mr Sutherland's** interesting contributions is about the relationship of engineering originality and scale. It is suggested that while engineers rarely invent basic forms, they do display originality when they adapt these forms to problems which by their scale bring in circumstances which were insignificant in small scale. The large-scale examples seem to demonstrate this point better. The scale is not absolute but depends on the amount of material used in relation to the problem.

140. The Paper indicates that specialization—one result of having considerable information—is one of the dangers facing the modern engineer. I support **Mr Savage** when he states that over-specialization could destroy the role of civil engineers, especially as most would agree with **Mr Horner** that one man must lead the team of specialists now used for large engineering jobs. Status has been mentioned by several contributors, and part of that prestige will have to be sustained by the engineer's contribution to the broad aspects of any civil engineering problem. It is difficult with the amassing of new information to keep a broad outlook, but unless we do, then other members of the interdisciplinary team will take over part of our work. That would perhaps be a pity for the efficiency of the work; for example, an accountant's idea of economics can be different from an engineer's, but not necessarily better. **Mr Horner** identifies the crux of obtaining status or being recognized as a professional when he states the standards required by the individual engineer.

141. It is interesting to note the consequent educational implications of this, which

are mentioned by **Mr Sparks**, **Mr Cook** and **Mr Ashley**. Many of the contributors seem to agree with my own view that more is required from the initial engineering education than the basic engineering theories. If this is so, then I trust that **Mr Smith** and other academics will delineate for themselves the qualities required, as many of the education establishments do, so that their curricula encourage and develop these qualities. The mores of the academy perhaps encourage staff to deeply study particular elements of civil engineering, and thus valuable and necessary advances are made. The point of § 12 is that the primary justification for science is to explain, but that of the engineer is whether the knowledge can be practically applied. It is necessary for the engineer to extend knowledge but always with the goal of practical application. Such engineering research is also required to impart the sense of what it is to be a learner, vital for any teacher. But a balance must be struck between the advances required, which are generally on a narrow front, and the broad understanding of the totality of engineering if undergraduate training is to be adequate for the modern civil engineer. To design the kind of education best suited, one must assess what in civil engineering is considered excellent, what are the criteria for judging competence, at what stage can education/training reach towards these goals, what qualities can education/training initiate, encourage and develop and what should it leave alone.

142. **Dr Wright** and **Mr Sutherland** both agree that design skills are important for the engineer, and pose questions for any teacher of engineering. **Mr Sutherland** asks if technical education is concentrated too much on providing knowledge, and says that an enquiring mind is needed. **Dr Wright** asks how imagination can be developed.

143. The definitions of imagination are many and varied, and if philosophers find it difficult to define, it is incumbent on me to be wary and brief. Engineers require a productive imagination controlled by rigorous appraisal and verification, the kind that Wordsworth described as 'reason in its most exalted mood'.²⁷ In using this brand, the engineer appears to have rapid judgement in reflecting on possibilities, which at best have an iconoclastic quality of remodelling experience or the priorities of the problem. It has already been argued that the malleability of civil engineering problems does allow such scope. If this is so in practice then the education curriculum must be arranged for such imagination to be developed. If, on the other hand, it is thought that civil engineering is a painstaking development from analysis to logical conclusion—and a substantial amount of engineering can be satisfactorily done in this way—then the development of imagination is not of high priority. If the latter view is taken, the engineering teacher solely inculcates knowledge and methods of analysis. I agree with the views of **Dr Wright** and **Mr Sutherland** that some educational devices are required for development of imagination. The word 'development' is used because it is felt unlikely that imagination could be taught as a lecture subject.

144. There are difficulties in providing these devices in the curriculum. Engineering requires considerable knowledge for appraisal and verification and as a basis for imagination. General engineering teaching is, as for science, divided into self-contained, well defined subjects so that the initial learning to a proper intellectual standard is amenable for the student. But some universities have managed to incorporate the learning of basic knowledge with the development of individual design skills. The tactics used are to study problems which are similar to real problems, but total rather than partial, so that they cut across those well defined teaching areas and admit of alternative solutions. This allows the student to find out and assess what information is required and then choose and verify his solution. This educational tactic cannot be condensed into a check list or into lecture form. Values need to be taught which rely on the student producing his ideas before the teacher can start to teach. Therefore project work either for individuals or small groups is required, with problems which are identical to reality in their totality and which ensure that the student himself must find out what is required. **Dr Wright**,¹⁶ **Mr Cook** and **Professor Black**²⁸ are three who touch on this aspect of engineering education.

145. **Bruner**,²⁹ **Wertheimer**,³⁰ **Medawar**³¹ and **Koestler**³² are a few of the educational-

ists who have examined this aspect of imagination. In a minor key, I believe that a teacher must allow to be seen the method by which he makes his first attempts at solving problems. It is unlikely to be that elegant display that comes only as a rational reconstruction of events and which is more a logical skeleton for verification rather than the initial ideas. Such educational tactics would allow for inter-professional projects, which are suggested by Mr Sparks and Mr Cook and which have been tried at some universities including Manchester, Bath and Heriot-Watt.

146. The flexible teaching instrument for such objectives is project work. This is used in many educational establishments. For example, at the Heriot-Watt University I have had a particular development of project work operating since 1960. A group of two or three students study an aspect of architectural technology which the students have not studied before, and which has not been given in a standard textbook. The subject is chosen by the students, but can be vetoed by the staff. A written report is given, with which experimental apparatus can also be submitted, and a 30 min verbal summary is given to staff and the remainder of the students, followed by questions. This generally cuts across subject areas and brings the student into intimate contact with practising professionals and others connected with the building industry. While this kind of project is mainly tailored for the later years, other projects, such as conceiving and building a small structure, are possible in the early years.

147. Projects, however, absorb time and this will influence the time allocated for lectures. A decision has to be made as to the most suitable means of making available material normally imparted by lectures. Many of the initial lectures are on basic material, and a resource centre such as described by Cowan *et al.*³³ would be useful. The skills of the engineering teacher would then be used at maximum efficiency. By these methods it may be that we can help to develop a mind active in elaborating and unifying all the different strands of civil engineering, active in the process of evaluative judgement, implicit and explicit, having the ability to recognize the core of the problem and possessing standards of values, a mind which strives towards excellence in practical and social terms. A rather terrifying goal for any teacher.

148. It has been interesting to note which parts of the Paper have been discussed by contributors, implying that in these areas this is an opportune time for discussing aspects of the nature of civil engineering.

References

12. ELIOT T. S. *The Rock*, Chorus I. *Collected poems, 1909-1935*. Faber & Faber, London, 1936.
13. BOTT A. N. *et al.* Wave power prospects for Mauritius. *Wat. Pwr Dam Constr.*, 1978, Dec., 32-39.
14. DASMAN R. F. *et al.* *Ecological principles for economic development*. Wiley, London-New York-Sydney-Toronto, 1973, ix and 252.
15. EDMONDS H. G. The use of physicists as engineers. *Physics Bull.*, 1965, 16, June, 228-230.
16. WRIGHT D. E. The use of project work in degree courses for civil engineers—the design project. Introductory note for meeting of ICE Education and Training Group held on 5 May, 1969.
17. BULL K. Public participation in the Lewisham traffic and environmental management studies. *Proc. Traffic and environmental management seminar*. Planning & Transportation Research Corporation, London, 1978, P165.
18. Environmental impact analysis. *Built Environment*, 1978, 4, 2 June (whole issue).
19. NUFFIELD FOUNDATION. *Small grants scheme for undergraduate teaching*. Nuffield Foundation, London, 1974.
20. COTGROVE S. *The engineer, professionalism and society*. General Education in Engineering, University of Aston in Birmingham, 1975.
21. PENNYCUICK J. *All England law reports*, 1966, 3, 404.
22. SACHS LJ. *All England law reports*, 1967, 2, 558.

DISCUSSION

23. LORD UPJOHN. *All England law reports*, 1968, **2**, 686.
24. DIPLOCK L.J. *All England law reports*, 1968, **1**, 497.
25. MINISTRY OF HOUSING AND LOCAL GOVERNMENT (SKEFFINGTON A. M. (committee chmn)). *People and planning: report of the Committee on Public Participation in Planning*. Her Majesty's Stationery Office, London, 1969.
26. INSTITUTION OF CIVIL ENGINEERS. *Education and training of civil engineers: report of the Chilver committee*. ICE, London, 1975.
27. WORDSWORTH W. The prelude. XIII.
28. BLACK J. *Education for engineers*. British Council, 1977.
29. BRUNER J. S. *Towards a theory of instruction*. Harvard University, 1966.
30. WERTHEIMER M. *Productive thinking*. Tavistock Publications, London, 1961.
31. MEDAWAR P. B. *Induction and intuition in science*. Methuen, 1969.
32. KOESTLER A. *Art of creation*. Hutchinson, 1961.
33. COWAN J. *et al.* Experimental learning unit for structural engineering studies. *Struct. Engng*, 1973, **51**, Sept., No. 9.