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'Engineers - The Supply Side'

POST-16 Technology Education Seminar

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1. INTRODUCTION

In February 1997, the Royal Society, Royal Academy of Engineering and Engineering Council jointly sponsored a seminar to examine the implications of developments in post-16 technology education for the supply of future engineers. The seminar focused, specifically, on the **motivation, preparation** and **formation** of engineers. It recognized that while education at any level is not solely about vocationalism, within the broader educational need lies a national economic imperative.

The seminar took as its starting point the recognition by the science and engineering community that weaknesses on the 'supply side' of the national skilled work-force, at all levels, are likely to adversely affect future national industrial performance. [1, 2, 4, 5, 6, 10, 11, 13, 14, 16, 17, 20.] These perceived weaknesses include:-

1. The inability of the science and engineering profession to attract a sufficiently high proportion of the more able students;

2. The inability of science and engineering to attract a sufficiently high proportion of women students;[9]

3. The need for more university departments to tailor their courses to match the increasingly diverse range of student profiles of achievement and potential at entry to higher education [11, 16].

4. The need for more course elements related to the practice of engineering such as design and design projects, team-work, problem solving, an awareness of social, economic and environmental issues, and continuous learning development.[12, 16, 21.]

The science and engineering community also recognizes that although these, and similar, diagnoses have been made in many reports published over the last forty or so years, it is only now, with imminent developments in 16-19 education and revised requirements for engineering courses in higher education, that opportunities are occurring to remedy the situation. [18, 21.]

Members of the seminar were asked to identify practical remedies to these weaknesses and to make recommendations for their implementation. This paper summarizes the findings of the seminar, the effectiveness of which will be dependent upon the commitment and collaboration of many parts of the education service. Copies of the full report of the proceedings are available from Nigel Thomas, Education Officer at the Royal Society by sending an A4 self addressed envelope. Comments on the issues raised by the seminar are welcomed and should be sent to the same address.

2. SUMMARY OF GENERAL RECOMMENDATIONS

Several general recommendations recurred throughout the seminar:

1. Identify and promote the '*culture of engineering*':

Engineering has its own distinctive culture of human purpose and achievement which has enabled and underpinned much of human progress and civilisation. This culture comprises particular knowledge and understanding, and particular ways of thinking, knowing and doing. It is of direct importance to the individual's potential for a lively and constructive role in society and their fitness to contribute to industry's power to create national wealth. The *'culture of engineering'* should be identified, recognized and used, consistently, in constructing the diverse elements of general and vocational education for engineering literacy and capability from primary education and throughout life.

2. Stimulate the '*engineering motive*':

Active involvement, by learners both young and mature, in the human, problem-solving, creative and innovative functions of engineering inspires a motive to innovate and bring about changes and improvements to the environment and to seek to acquire the skills, knowledge and understanding for success at the earliest possible age.

3. Foster the basics of engineering:

The intellectual and practical skills, knowledge and understanding comprising the *'culture of engineering'* provide capability for use in adult life as a whole. Such a capability should be built on the basics of fluent mathematics, science, design, problem-solving, practical skills and innovation, from primary school onwards.

4. Recognize the need for 'whole-life' stimulation and education for engineering:

Individuals' motivation and preparation for engineering cannot be simply switched on at age 18 and finished at age 22. Changing, and new, technologies are an inherent part of engineering and there is a need for re-training and continued learning throughout life.

5. Exploit the expansion in numbers (the 'Long Tail'):

Some further and higher education departments have realized the necessity for broader skills to be taught and are acting to strengthen these aspects of their courses. The further education and higher education sectors need to monitor and adapt to the increasingly diverse range of levels and types of qualifications at entry to engineering courses. It is essential that a closer match is achieved between course design and students' profiles of achievement and potential, which should be sought by admissions tutors. Academic and vocational pathways and options must be kept open throughout 16-19, further and higher education.

6. Build on success: Just as engineers identify and build on the success of their predecessors, so successful syllabuses, examinations, teaching methods and external support systems should be identified, promoted and used.

7. Teaching quality:

From primary to higher education, the importance of subject knowledge and teaching/learning methods is paramount. Consecutive sectors should learn from each others' successes in motivating and preparing students of both sexes for engineering capability. The need for sound teacher training to include the *'culture of engineering'*, and for basic research into its pedagogy should be promoted.

8. Initiatives needed to produce outcomes:

A coherent framework, based on the '*culture of engineering'* and comprising principles for course design and guidelines for support materials and for interactive connections between schools, further education, higher education, and industry should be established and used to identify the initiatives now needing to be taken by responsible bodies to improve the effectiveness and quality of the system which controls the flow of personnel into the engineering profession.

3. RECOMMENDATIONS FOR ACTION

In order to translate these general recommendations into practical effect:

a) their particular implications for primary and secondary education, 16-19, further education and higher education need to be specified and initiatives for action identified;

b) a comprehensive statement should be made on the *'culture of engineering'* which will provide a common foundation for the proposed initiatives;

c) the agents for change need to be identified and invited to act.

1.1 PRIMARY AND SECONDARY EDUCATION

The inter-dependent theory, practice and purpose of the *'culture of engineering'*, should suffuse general education, and feature as part of a redesigned concept of technology in a revised National Curriculum.

Key Stages 1 and 2

These are the most impressionable ages of childhood.

Motivation and awareness:

- Pupils should be given successful experience of inventing, designing and making to stimulate the '*engineering motive'*.
- Well designed teaching support materials should be provided to help students of both sexes see not only the fun aspects of engineering but also its diversity of purposes, particularly in relation to improving the quality of life and the mutual support given by mathematics and science.

- There should be a closer connection between the subjects of 'science' and of 'design and technology' in the National Curriculum.

Key Stages 3 and 4

The engineering motive:

Children are now beginning to think more seriously about career directions and are heavily influenced by family and the media.

- The motivating personal experiences of designing and making should, increasingly, be applied to solving problems drawn from the real world. Employers are often finding that it is well worth collaborating with schools to find solutions to their problems.

- Supporting services and guidance materials should be made more widely available to enable 'real world' engineering to be experienced in all schools. The *'Neighbourhood Engineer'* and *'Scientist in Residence'* schemes should be improved in quality and coverage to assist with this objective.

The basics of engineering:

Design and Technology gives pupils experience of 'combining their designing and making skills with knowledge and understanding, particularly in science and mathematics, in order to design and make products'.

- Syllabuses should require an explicit and increasing dependence on this 'knowledge and understanding', including that of mathematics and science in the activities of 'designing and making'.

- As a corollary, the subjects of mathematics and science should, increasingly, be shown to have real uses in the world of engineering.

Assessment

In order to help young people to gauge their potential and to choose their post-16 pathways, assessment at age 16 should be designed to contribute to the range of evidence of the engineering abilities set out in the SARTOR documents, (Standards and Routes to Registration), which set out the requirements of the Engineering Council for individuals who wish to register as Chartered Engineer, Incorporated Engineer, or Engineering Technician.

1.2 AGE 16 - 19

This is an age of uncertainty. Young people often find difficulty in committing themselves to particular career directions. Some are uncertain of their adult interests; others of their abilities and potential. A few are more certain and confidently select courses which will lead them to particular careers. For others it is a time for finding out about aptitudes, ambitions and potential capabilities. There is a danger that the pattern of provision of courses and subjects, by default, shuts off career options prematurely.

The 16 - 19 curriculum:

- Curriculum provision should be sufficiently broad and flexible to meet the demand for more 'rounded' engineers and, at the same time, maintain the *'culture of engineering'* as an element of general education for all. Narrowing the content and the teaching and learning styles of courses may, unnecessarily and prematurely, close off routes to further education and training.

- Courses which set out to prepare future engineers should not be narrowly centred either on pure mathematics and science, or on manufacturing. Rather, they should be broadly based on the *'culture of engineering'* and maintain a balance between theoretical and practical knowledge and its application to the problem-solving inventive processes of designing and making.

- Units making up the 16-19 curriculum should be

    1. large enough to provide a coherent and complete study discipline;
    2. small enough to provide choice and flexibility;
    3. structured with 'valence' links to enable units to combine to form complete educational programmes;

d) and allow for valid, reliable, synoptic and specific assessment.

Some form of 'baccalaureate' approach, with a broad-based 16-19 curriculum, would be the preferred structure for combining academic rigour with coherence and flexibility.

- Regardless of curriculum structure, educational objectives of courses should be set out clearly both for their students and for higher education so that it may design and build courses which progress with coherence and consistency. Such objectives should be based on:-

The engineering motive. With increasing maturity, motivation for engineering is stimulated not only by involvement in the creative nature of its activities but also by the realisation that engineering presents a challenging and high level discipline which centres on the achievement of human purposes and ideals, and which provides methods and intellectual resources in support of such achievement and that it is not an easy option for the less able student,

The basics of engineering. The inter-dependence of scientific and mathematical understanding with problem-solving and inventive manufacturing skills.

Teaching and learning:

The timelessness of the *'culture of engineering'* provides a rationale for selecting the content of courses but it should be tempered by the limited 'shelf-life' of engineering knowledge.

- Students should be well prepared for life-time learning and continuing professional development by 'learning how to learn' as much as by acquiring currently important facts and principles.

- Students learn more effectively when they are actively involved both in the **learning process** and in the **processes of the discipline**. Students should be given increasing responsibility for taking charge of their own studies.

- Courses should contain open-ended, constructive, inventive, and investigative practical project and assignment work, involving groups of students. This stimulates interest, provides training in intellectual, interpersonal and physical skills of team working and problem solving, which are of value in all walks of life, and need to be integrated into mainstream programmes of study.

- Fluency and confidence in the knowledge and use of mathematics and science comes with repetition and practice but deeper understanding comes with experience of transferring concepts and principles to new contexts and applications. With recent developments in information technology, students should be able to conduct realistic design investigations and use powerful mathematical software to help remove the artificial nature of the mathematics taught. Ability to apply theoretical and practical knowledge to solving design problems comes only through designing and testing products. Courses should provide a balanced spectrum of learning experiences.

- Support and guidance should be developed to help teachers construct and deliver such appropriate courses.

Assessment:

- Combinations of courses which lead into higher education in engineering should provide evidence to admissions tutors of a student's competence and potential across the whole profile of abilities which a particular degree course in engineering is designed to develop, including an indication of student capabilities in problem-solving.

1.3 HIGHER EDUCATION IN ENGINEERING

The expansion of higher education has created a large number of courses aiming to produce the highest calibre of engineers. However, the types and levels of abilities of many students recruited to some of these courses have resulted in undue levels of failure, or under-achievement.

- Higher education in engineering should accept three realities;

    1. first that the system is already producing a sufficient number of engineers, overall;

    2. second that there sometimes appears to be a mismatch between the learning objectives of engineering courses, as a whole, and the range of skills needed in national employment, and;

    3. third, that it is preferable for individual engineering courses to be tailored to meet particular employment purposes and identified student needs and abilities, than for all to aim at a single, high level, target with a consequently uneven quality of graduate output.

- SARTOR sets out specifications for courses, but 'fitness for purpose' means that more course leaders, with the explicit support of their institutions and of the funding mechanisms, should design 'quality assurance' based systems of engineering education rather than relying on the traditional 'quality control' of terminal examinations.

- Higher education departments should design, coherently, selection criteria, course content, learning experiences, outcome targets, and final assessment schemes for their particular courses. Many departments are already working to improve these aspects of their courses, but there is still much work to be done.

In particular, courses should:

- integrate within them design, teamwork and inter-personal communication skills;
- concentrate on problem-based learning, and its particular motivation to develop awareness of social, economic and environmental issues;
- provide an adequate number of design projects and, generally make courses more motivating, stimulating and exciting [16];
- Admissions decisions should require evidence of students' potential to meet the challenges of all aspects of an engineering degree course, including performance in problem-solving, design projects, application of knowledge and understanding, as well as fluency in the basics of mathematics and science.
- Universities should make publicly clear the educational objectives of each of their courses, how the entry selection criteria match with those objectives, and what evidence will be sought for making selections of students.
- Higher education will need to work more closely with schools if there is to be improved coherence and progression through the system. Schools need support for understanding the nature of 'engineering knowledge' and how it is applied to real problems but schools can help universities develop more exciting approaches to the study of engineering.
- Of the utmost importance is the need for universities, further education colleges, schools and examination boards to work together in the setting of syllabuses and assessment schemes, at age 18 or 19, which will determine the nature of learning at age 16-19, and in establishing the criteria for assessment at A Level and Advanced GNVQ, which will also contribute to admissions criteria.

APPENDIX I: *'The culture of engineering'*

Engineering has been, and is, a key and integral factor in the development of mankind. The engineering problem-solving achievements in successfully recognising and meeting human needs have led the development of many civilisations. Over thousands of years, the development of farming and community health, through irrigation and the control of water supplies, the harnessing of energy by wind and water mills, buildings, transport and communication systems, has enabled mankind to settle in social comfort and security and develop its creative arts, religions, languages and communications, sciences, transport and architecture. That humans have employed engineering so successfully, for so many thousands of years, and that it still provides the means of human endeavour and development in every field should feature in the National Curriculum as part of our heritage. The *'culture of engineering'* might be summarized as:-

'the exploitation of practical and theoretical knowledge and understanding, and the application of the intellectual and physical skills of enquiry, observation, invention, design, and manufacturing in the pursuit, and achievement, of human needs, purposes, beliefs and aspirations.'

Although many contributing elements of knowledge, understanding and skills are contained in the National Curriculum, it is the **holistic** *'culture of engineering'* on which civilisation has grown and which needs to be made explicit in education. Its virtual omission from the programmes of study of History, Geography, Science and even, in its historical perspective, in Design and Technology should be remedied in the interests both of cultural awareness and of industrial economic necessity.

The statement on the *'culture of engineering'* would have a number of sections, such as:

- **the history and human purpose of engineering**, its success in enabling, and becoming an essential part of, the development of human civilisations;
- **the forces which drive engineering development**, in terms of human needs, wants, purposes, expression and aspirations, values, care, responsibility, wealth creation and resource exploitation;
- **the engineering processes** of problem-solving, designing, and manufacturing, distinguishing between 'normal' and 'radical' design (Vincenti), between iterative and linear (right-first-time) design, and the 'Russian doll' view of the complexities and hierarchies of major design projects;
- **the nature of engineering knowledge**, distinguishing between theoretical and practical knowledge (know-how), between engineering and applied science, between the 'imaginative, controlled curiosity' of science and the 'creative applications of scientific principles' to technology (Dainton), and between mathematically based and experience based design concepts;
- **the origins of knowledge** useful for engineering (generated by scientists, by theoretical engineers, or by practical engineers);
- **engineering as enterprise**, innovation, manufacture and commerce;
- **engineering as service**, support for medicine, science, agriculture, business, home and leisure;

Setting it out like this, the *'culture of engineering'* could be drawn upon appropriately, and consistently, for all the actions proposed in the recommendations.

APPENDIX II: Agents for Change

The agents for change in the system include:

- Engineering professors, course planners, admissions tutors;

- University vice-chancellors and senates;
- Authors and publishers, both for degree courses and for courses up to age 19;
- Examination boards, officers and examiners;
- Accrediting bodies, the Qualifications & Assessment Authority (QCA);
- OFSTED and other inspection/assessment bodies (e.g. FEFC, HEFCE etc.), and the Teacher Training Agency;
- Government departments including the Department for Education & Employment (DfEE), DTI, funding councils.
- Teachers at all levels.
- SATROs, Design & Technology Association (DATA), Association for Science Education (ASE), British Association for the Advancement of Science, etc.

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