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The Task for the Educator

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5. THE TASK FOR THE EDUCATOR

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Unreal attitudes

The first task for the educator is to get someone to educate. It is extraordinary how, in a time of shrunken classes and empty places in academic departments of engineering and metallurgy, this elementary point is overlooked in discussions about the teaching of these subjects. Arguments all too often become unrealistic because they are built on an assumption that there exist captive audiences available to the educator to mould as he wills, an assumption that is as far from reality in this permissive and feather-bedded age as the Victorian mechanics institutes are from the student unions.

Even when they are supposed to address themselves to the problem of the empty places, such discussions tend to drift away into a make-believe world. A voice goes up: 'a year in industry, between school and university, would do the students good'. That may well be so, but the setting up of an extra hurdle between the student and his degree, in the applied sciences, would inevitably deflect many school-leavers away into the pure or social sciences, or the arts, where the ambitious ones could maintain their academic momentum without interruption and the more cautious ones could continue to enjoy the familiar comforts of an academic environment. The cry 'a year in industry first' pre-supposes that the school-leavers are already committed to eventual entry into industry, an assumption which for the most part is quite untrue in the conditions of today. I believe that if such a requirement were introduced, it would in fact cause them to make up their minds not to go into industry or subjects related to it.

Once a discussion on empty places is side-tracked in this way it usually then ends up totally derailed by calls to 'make university courses more practical', or 'teach more about the widget-making industry' or 'train them in the techniques of knurdling!' I am glad to say that the professors of the applied sciences, who are usually the only audience for such remarks, generally adhere robustly in the face of this to their views that you cannot apply science until you have some science to apply; and that general potentiality rather than specific skill is the quality they want to develop in their students. But nevertheless, such remarks do not make their task any easier when trying to increase the attractiveness of their courses, in competition for students against their colleagues teaching in the other sciences or the arts.

To see the real position, let us turn to some figures. The problem is one for the applied sciences generally but, in this conference dedicated to the memory of Dr Rosenhain, I will deal only with metallurgy and materials. Over the period from 1969 to 1974 the total number of students admitted annually to degree courses in metallurgy and materials dropped, from nearly 700 initially to only about 530 in 1973, with a slight recovery last year to nearly 600. Over this same period, the number of available places rose, from about 860 initially to about 960 last year, so that on average over one-third of the places are empty at the present time. While the subject 'materials' has made headway, increasing its intake from about 110 in 1969 to slightly over 200 last year – undoubtedly a result of the development of 'materials science' as a new academic field – that of 'metallurgy' has dropped away alarmingly. In 1974 it attracted only about 200 students, compared with 440 in 1969.

Why have the numbers been declining so much? Is industry overstaffed with metallurgists and materials engineers? If that were so, one might expect to find their salaries to be lower than in comparable other professions, but I do not believe that they are, to any significant extent. Furthermore, other countries such as Japan seem to employ many more, in proportion, than we do. And in any case the Chairman of the British Steel Corporation has said that in the course of a generation it will be necessary to find 180000 metallurgically minded people to run the Corporation's new processes and plant. Even a Methuselah could barely span a generation long enough to square this demand against the supply.

The answer becomes clearer when the problem is taken in context. Some of the decline is undoubtedly a reflection of that in the exact sciences generally, which are too sharp, hard and clear for today's indulgent tastes; and much of the rest can only be part of the general reaction against industry, which still bears the image of the cloth cap and sweat rag, as well as being the main battleground of today's social and political upheavals. But there is, I think, a third factor which influences the choice of the more discerning and serious student; and this is concerned with the range and scope offered by the various subjects he might elect to study.

General education or vocational training

The range of intellectual horizons opened up by a course of study, and the scope for branching off into various careers afterwards, raises again the question of education versus vocational training. I believe strongly that undergraduate education should be very broadly based and aimed to develop general potentiality, not particular specializations. In the physical and engineering sciences I believe that a good understanding of mechanics, electrodynamics, thermodynamics and atomic structure are absolutely essential and that, in an undergraduate course, these should never be skimped to make room for more directly technological subjects. The concepts underlying the physical and mechanical sciences, such as the nature of strain, or entropy, or electrodynamics, or wave functions, are difficult to grasp and, if not mastered during one's student days, when both the opportunity and the ability to absorb new ideas are at their most favourable, it is unlikely that they will ever be really understood later, in which case one will be equipped with an incomplete and fragile set of intellectual tools for tackling the work of a technological career. By contrast, it is I believe much less difficult to add on, later, to a sound general scientific foundation, the detailed knowledge by which one becomes an expert in a specific technical field.

This is fairly well understood in academic circles but, from the standpoint of the teaching departments in the applied sciences, it raises problems because it so often leads school-leavers to choose instead to read the 'basic' subjects such as physics, chemistry and mathematics, at least for their first degrees.

There is in fact a great deal of sense in this. In many ways, I believe that the ideal course would be to start with a first degree in the basic sciences – perhaps an 'ordinary' degree taken after two years – followed by a second degree – which could be an 'honours' degree – which in the case of those aiming at the technological professions would be taken in the appropriate applied and engineering subjects.

Needless to say, such a proposal faces various objections and difficulties. I do not take seriously those, both in industry and in the applied sciences, who argue that there would not then be enough time for the students to learn their technological subjects to the required professional depth. As I have said, the aim should be to provide future potential, not present skills, particularly as the graduate will supplement his few years of degree studies with something like forty years thereafter of direct experience 'on the job'. In any case the charge of lack of time cannot be seriously maintained in this country, when we spend so much on postgraduate training in research, an outpouring of time and money which, for all but a rare few of students, could be much better used in extending the advanced formal education to something more like that in most European countries, or in the U.S.A. where an 'ordinary' Bachelor's degree is usually followed by an 'advanced' Master's one. There is a great and general problem for our system of higher scientific education here. It will not be solved readily and it may be that, for some time at least, we shall have to settle for lesser solutions that lie within the framework of the present academic structures of the country.

A second problem is, how do the students ever become acquainted with the applied and engineering sciences, sufficiently to consider at some stage transferring into them and making their careers in industrial technology? By and large, there is still very little awareness of these subjects among the schoolmasters who guide their school-leavers; and, after the failure of the many campaigns to create such awareness, I think we must accept this as an enduring fact of life. In any case, even the aware schoolmaster may advise his pupils to 'get a sound education in the basic sciences first, and then branch out from there' and from their point of view it must often be excellent advice.

If, then, we have first degrees in the basic sciences for all science students, may not the above state of affairs simply persist in the universities and such courses become in their range of interests merely school 'seventh forms'? The answer, I think, is to have *all* the scientific and technological departments participating in those basic scientific courses. I do not mean by this that they would be teaching their own technologies (although they might want to refer to them briefly to illustrate the working of basic scientific principles in practice, such as for example the principles of surface tension as used in froth flotation of metallic ores). No, I would want them to be teaching those parts of basic science, integral to the fundamental courses, of which they have particular experience. For example, the mechanical engineer might teach classical mechanics, the materials scientist teach the structure of matter, and the metallurgist teach thermodynamics. In this way the first-degree students would become acquainted, if not with the technological subjects themselves, at least with representatives from those subjects. The ice would be broken and the students would have a wider range of people from whom to seek advice on their future choices of subjects and careers.

If I may speak here briefly in support of my University, I do think the Cambridge Tripos system has great advantages from this point of view, with its division into a broadly-based Part I and a specialized Part II, and with its general entry into a common set of courses for undergraduates in Natural Sciences Part I, including the first-year course on crystalline materials of which the Department of Metallurgy and Materials Science shares a good part of the teaching. The majority of the physical scientists in Cambridge go through that course and a satisfactorily large number of them elect to continue with metallurgy and materials science in their second and third years.

Metallurgy and materials science

A special problem about metallurgy and materials science, as an integrated discipline, is that it has equally important links with three different major subjects; physics, chemistry and engineering. Of course, a lot of its fascination stems from this, and a good deal of the justification for having metallurgy as a distinct academic subject rests on its equidistance from these other subjects, but it has rarely been able to form close alliances with any of them without weakening its links with the other(s). There is thus a tendency for it to break up into materials science associated with physics, chemical metallurgy associated with chemistry and chemical engineering, and materials engineering associated with general engineering. I do not think these problems will be solved until we have single Schools of all the Sciences with much more commonality between the courses. In such Schools the students would all take a selection of 'general purpose' courses – taught by representatives from all appropriate subjects – as well as some 'single subject' courses, at all stages of their undergraduate education.

There is a second, and related, problem about metallurgy and materials science, which concerns the career of the graduate in industry. Is metallurgy a primary or a supporting technology? The answer depends on what kind of metallurgy we have in mind. Chemical metallurgy is undoubtedly a primary technology, since there is a major industry – that of basic metal production – devoted to its output, so that it is entirely reasonable for an outstanding chemical metallurgist to expect that he might eventually have charge of a major enterprise in this industry and be responsible for its general policy. But the physical metallurgist, the materials scientist and the materials engineer, is not usually in such a position. Of course there are industries that specialize in metal and alloy manufacture where he can play a leading role, but in most parts of the industrial sector his position is more likely to be that of assistant to someone else who is producing engineering goods and services. The materials man can contribute a lot to, say, nuclear reactors, or aircraft, or computers, or chemical plant, but is unlikely to be given overall responsibility for the project, which generally and rightly belongs to the engineer. He is unlikely to reach the top of the engineering tree in such industries, unless he abandons his specialist position and converts himself, both professionally and by experience and interest, into a general engineer.

I think this may be a reason why some of the modern physical metallurgists and materials scientists have, like so many physicists, preferred to seek careers in academic life; they may have felt that the road to the very top, where they could be in charge of projects and technical policy, was not really open to them in most of industry.

Relation to engineering practice

The relation of physical metallurgy to engineering practice raises other problems for the educator. How should one present the science of materials to the engineer? It is important to remember that the 'mainstream' engineer – whether civil, mechanical, electrical, chemical or aeronautical – is a *user* of materials. All his talents and interests are devoted to engineering goods and services. For him the problem of an engineering system is to achieve a satisfactory performance, to have it respond with good outputs to the stimulus of its applied inputs. So long as this is achieved, the inside of the system can be a 'black box', so far as he is concerned. Thus, for him, materials are things that fill the space of the system with certain properties, preferably expressed in terms of a few simple numbers, and which cost money.

I think that this point is sometimes overlooked in courses on the science of materials for engineering students. It is only natural for an enthusiastic scientist to wish to explain his subject, as it excites him, to his audience; for the physical metallurgist and materials scientist to explain from the phase diagram how alloys are formed, how crystals diffract X-rays, how atoms move about in solids, why metals conduct electricity and insulators do not; but are these the things the general engineer really wants to know?

They are the things important for the designer of *materials*, but the engineer designs *goods*, not materials. Most of the science of materials, when it has been concerned with applications, has been aimed at new alloys, improvements by heat-treatment, new microstructures such as fibre-reinforcement, and new fabrication processes. What we may have overlooked is that there is a potential new science, hardly developed yet but of direct relevance to the engineer, which is the science of the performance of materials in engineering service. Perhaps the best example of this is fracture mechanics, developed from A. A. Griffith's pioneering scientific investigations into the nature of brittle cracks, which has now grown into a standard practice in engineering design, based on the requirement that the material in an engineering component should have a minimum fracture toughness, the value of which is governed by the geometry of the component and the conditions of its service.

Need for a science of materials in service

If it were possible to deliver to the engineer various design procedures as explicit as this, for dealing with other problems of materials in service – such as metal fatigue, stress-corrosion cracking, or fretting failure – physical metallurgy and materials science would then be able to make new great contributions to engineering practice. But we are still a long way from achieving this. The necessary science is not yet there.

Many research metallurgists accept this but then go on to delve more deeply into the basic atomic processes of fatigue, or corrosion, etc. Admittedly, we do not yet have a complete understanding, at the atomic level, of the above complex forms of failure in engineering materials, but it may be that such an atomic understanding will not help to solve the practical problem and that the more important thing that is missing at the present time is a rigorous and sophisticated applied science of the uses and service of materials. Let us remember that the application of fracture mechanics does not depend on atomic concepts but on an understanding of the mechanics of a crack in a medium characterized only by its general elastic properties and its measured work of fracture. Similarly, from the practical point of view, the most important scientific discovery about metal fatigue was made long ago, i.e. that this is a type of plastic failure at the surface. A simple knowledge of this alone leads to many useful points in practice, e.g. the importance of hard surfaces, avoidance of soft zones, and minimization of tensile stresses in the surface.

I believe that there is great scope now for taking the existing 'pure' science of materials, as we already know it, and building from it a large new applied science of the performance of materials in service, one that will enable the engineer to get the best out of the materials available to him, even to the extent of encouraging him to adapt and transform his traditional design and constructional procedures to suit the properties of these materials, and to ensure that he will not be disappointed in practice through the unwonted failure of his constructions.

I believe that one of the most exciting challenges now, to the educator in the materials field, is to establish and teach to engineers a 'science of materials in service', comparable to the quite different 'science of materials for service' which he now teaches to metallurgists and materials scientists.

Discussion (Chairman M. E. Hargreaves (*Melbourne University*))

A. Kelly (*National Physical Laboratory*)

For a few more days I can speak as a user, rather than as a producer of trained metallurgists. I want to make a point which I have not yet heard made in this discussion; I want to approach