POSTGRADUATE RESEARCH TRAINING—CULPRIT OR SCAPEGOAT

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There is very little doubt that university postgraduate training in the sciences is under widespread, critical scrutiny, verging on downright attack. Although what I have to say reflects the situation in the U.K. the questioning is worldwide, as exemplified by the recent study in the U.S.A. by the National Science Board[1]. One of the main pressures for re-examination comes from industry, whose charges can be condensed into the blunt theme that there are too many Ph.D. students, whose training not only bears no direct relation to national needs, but also brainwashes them against an industrial career. In the U.K., such observations blend well with Government thinking in a financial crisis; in the recent words of a British Minister[2], 'We have set it as a major objective of our policy that science should be harnessed to the job of earning our living as a nation. . . . We have adopted a frankly commercial approach to our teaching of science and I make no apologies for having done so. It is absolutely no good spending hundreds of millions of pounds on self-generated science projects, or those which earn Nobel prizes and world acclaim, if industrial competitiveness is neglected in the process'. In the U.K. the subject was expanded in some detail by the Swann Committee[3], whose report on 'The Flow into Employment of Scientists, Engineers and Technologists', appeared in 1968. Of all the sciences there analysed, chemistry seemed to come out the best in respect of the supply of Ph.D.s to industry. Even during the period of very rapid university expansion in the U.K., with the consequent heavy demand for academic staff, recent figures show that about 40 per cent of chemistry Ph.D.s entered industry[4]. Now that the university staff outlet has slowed to a trickle, it was reasonable to suppose that the chemical industries' grumbles about postgraduate recruitment would be still further ameliorated by the larger proportion of Ph.D.s available for them. It was all the more alarming, therefore, when an industrial spokesman recently inveighed against the over-production of Ph.D.s by British chemistry departments, in the light of future research and development needs[5]. This rather sudden *volte-face* from previous industrial complaints about lack of supply, seems somewhat surprising and it is, perhaps, natural that academic reaction has included dark hints that university chemistry departments are being cast in the role of scapegoat for industrial planning deficiencies. However, a more pragmatic and fruitful response is to examine the problems on their own merits, studying the necessity for changes, while putting forward the universities' case equally forcefully and bluntly.

The objects of Ph.D. training from the student aspect are various and

interlinked. Material presented at the undergraduate stage has inevitably to undergo a tidying up process for logical presentation and coherent progression from concept to concept. This facilitates understanding and transmission to the undergraduate student, but inevitably 'sanitizes' the untidy blend of inconsistencies, false trails, critical analysis, blatant errors, irrational inspirations, logical deductions and exhilarating mental sunbursts that we lump together in the deceptively dead-pan term 'research'. It is impossible to teach this activity by talking about it and direct participation is the only means. It is not only creative but self-creative. No one who has undertaken research supervision can fail to have been struck by the change from a tentative largely passive receptivity to confident self-starting productivity after three years as a research student. The build-up of self-confidence, self-esteem and intellectual awareness has been impressive. During the process he has inevitably made mistakes, an essential part of the maturation process, but he has been guided, not penalized, by them. In the synthetic field a dramatic highlight is his first production of a new compound, a novel concatenation of atoms never before obtained but now conjured into being by a fledgling research student—it makes him feel like God. On a more earthy vocational plane the research student hopes that the skills and mental processes absorbed will increase his market value and potential and, of course, there is always the considerable social cachet of the 'Doctor' prefix. There is also the feeling that the Ph.D., a virtually international distinction, will increase the range of his options, not only industrial but also academic. His feeling that the possession of a Ph.D. will give him a competitive edge is reinforced by the presence of a plethora of doctorates in the higher echelons of chemical industry.

The same amphibious blend of intellectual satisfaction and earthy self-interest is also apparent in the supervisor. The intellectual stimulus of a basic research problem is inextricably bound up with the cognate attractions of recognition and advancement. One method of optimizing the desired healthy research achievement is to attract research students, but their use as mere mindless 'pairs of hands' would be self-defeating for the educational aspect of research training. It should be self-evident that worthwhile post-graduate research work is more likely to emerge when direction, training and discussion are efficiently blended by the supervisor. Further, research supervision has a salutary and revivifying effect on his teaching at both undergraduate and postgraduate levels; at the very least it provides initiative to keep up-to-date.

With these statements of high ideals the industrial critic has little patience. His accusations against postgraduate research training are varied, wide-ranging and sometimes contradictory. A summing-up of frequently-repeated opinions would include the following. University postgraduate research problems are eminently predictable trivialities on mundane and parochial topics, mere straightline extrapolations or interpolations from known phenomena. Many university problems are too rigidly narrow and develop a blinkered and restricted mental attitude in the research student. The high certainty of the Ph.D. degree creates an easy-going and uncompetitive atmosphere. The academic supervisor consciously or unconsciously brain-washes the postgraduate student against industry and makes an academic–

industrial transition unnecessarily painful. As a corollary, the nature of industrial thinking goes by default leading to a complete blank both in economic awareness and the high-pressure competitiveness involved in the exploitation of chemistry for practical ends. Postgraduate training is regarded as a self-perpetuating system for academics with little concern for the need to produce industrial pacemakers. In short, academic research is a non-productive drain on the national expenditure. These statements have been deliberately framed in an extreme version, and it would be misleading to imply their general acceptance. On this subject, as others, industry speaks with many tongues. To set these accusations in context the seeming gap between industrial and academic chemistry in the U.K. is much more apparent than real and the mutual relationships are considerably closer than in other sciences. However, it is clearly important to examine the charges in detail.

The construction of chemistry to its present towering structure has been, and to a considerable extent still is, a product of academic research. This colossal underpinning is the foundation and sourcebook for industrial chemistry. There is no guarantee that an item of seemingly pure ivory-tower dilettantism will not be utilized and extrapolated by a later industrial theme. In these days of selling 'effects' rather than compounds, even the most contemptuously neglected, academic lame-duck of a compound can overnight blossom forth into a cosseted industrial money-spinning swan. For example, bipyridyl was an academic curiosity until the herbicidal effect of its derivatives focused industrial attention on it; the enormous background of pyridine chemistry painstakingly accumulated by generations of academic workers was waiting ready made to be tapped. Spectroscopic techniques now standard in industry were developed academically and the corpus of knowledge acted as pacemaker, first for routine instrument production and then introduction into industrial laboratories.

However, academic staff, at least in chemistry, are well aware of the benefits accruing from extrapolating their own interests to an industrial application or starting a new line deliberately cognate with an industrial field. These cross-connections are growing steadily, supported directly by interested firms themselves and by the introduction of research studentships deliberately restricted to this kind of cooperation.

The charge that postgraduate training turns research students away from industry and keeps them in the academic womb was one investigated by the *Swann Report*[3] which showed that chemistry was the least culpable in this respect. A more detailed conjoint survey[4] by every chemistry department in Britain on the present position of every individual Ph.D. produced over the ten years 1958–1967 (a period of unprecedented university expansion) has made this point even more clearly. The case of induced antipathy towards industry in chemistry Ph.D.s is certainly not proven.

In the majority of chemistry departments in the U.K. the introduction of coursework in addition to research training, as part of the Ph.D. work, is now very frequent. These are used both for inculcating extra technical expertise and for introducing broader themes, especially those with industrial implications. The invitation of industrial lecturers to talk on these latter topics acts as a useful chink in the academic armour. This is not to imply

that postgraduate research students are uninterested in industrial matters. On the contrary, more and more are showing a lively interest not only in industrial chemical research and its organization but also in the cognate managerial and financial techniques. This is shown by the annual, large shoal of postgraduate chemistry applicants to the graduate courses run by the Careers Research and Advisory Centre. These serve as an intensive introduction to the problems and issues of industry, commerce, management and technical entrepreneurship. This popularity shows that the provision of such intensive and enjoyable courses should be amplified and plans are now afoot for such an extension involving the Scottish Chemistry Departments in collaboration with chemical industry. In planning such courses a clear idea of industry's needs is necessary and industry has frequently been diffuse and woolly in providing such information.

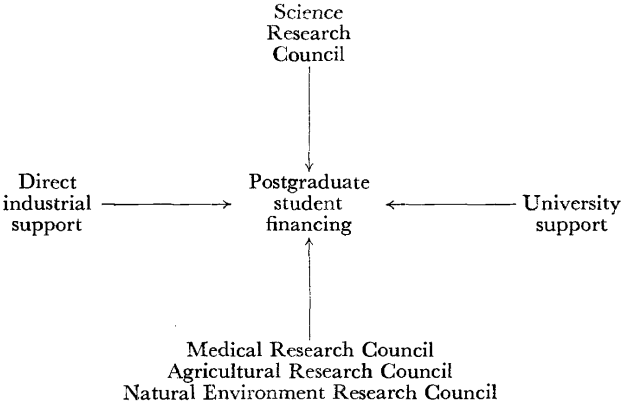

Figure 1

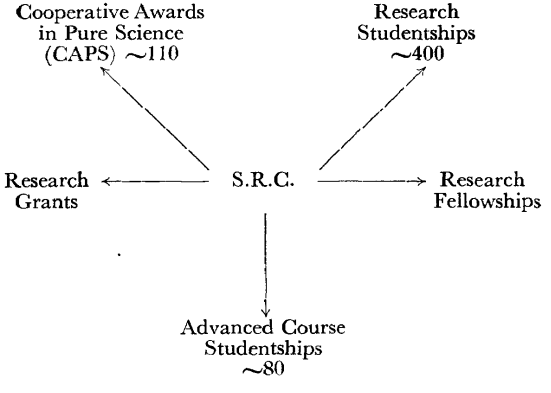

Figure 2

The warnings of over-production of Ph.D.s in chemistry prompt an examination of the sources of funding for chemistry postgraduate students.

This is shown in a condensed form in *Figure 1*. Of the sources there shown, about half the total support derives from the Science Research Council and the bulk of the remainder from direct industrial support usually negotiated individually by university staff members. *Figure 2* shows the main categories of Science Research Council support to over seventy British chemistry departments, involving the provision of research studentships and the newer Cooperative Awards in Pure Science which are restricted to approved joint projects with industry. The fact that chemistry takes more than half of this latter type of studentship does not suggest hostility to industrial interests in chemistry departments.

If pruning is inevitable it could be tackled in a number of ways. A straight cut in S.R.C. studentship numbers all across the board would be administratively simple but would basically be begging the problem. Egalitarianism is a soothing creed but everyone concerned would admit that not all centres have the optimum concentration of expertise and facilities necessary for the most efficient postgraduate training (everyone concerned naturally includes their own institution among the elite!). If cuts are inevitable, it would seem logical to subject the awards of research studentships to the same stringent examination that is already extant in the awarding of S.R.C. research grants, even to the extent of designating certain areas of work for preferential support as has already happened in the research grant area (the administration of such a scheme would certainly be a hot potato). If industry is highly concerned about Ph.D. numbers, it could lower the number by constricting its own support, although this poses its own problems by weakening the desired industrial–academic links. Any such cuts must take account of the effects on the academic research output and its desirable, vitalizing influence on university teachers. A transfer of the funds saved on research studentships to the provision of more technician help would be a palliative but not a complete solution. In particular, the loss of research student help in undergraduate teaching would be serious.

Such cutbacks are not without their own inherent dangers. A decade ago in the U.K. the Willink Committee on Medical Manpower recommended a cut in the number of students admitted to medical schools and the chronic shortfall of doctors is now a continuing problem in the U.K. Killing the goose that lays the golden eggs would be an ironic consequence of an attempt to turn geese into Swanns. The shrinkage in science student numbers generally in the U.K. and the deterrent effect of the warnings from industry as far back as school level might bring their own nemesis.

The disparity in the numbers of chemistry Ph.D.s and the industrial positions available has been assessed only on the basis of research and development requirements (naturally enough since this represents the obvious industrial/academic interface). However, as already mentioned there is a growing awareness and attraction among chemistry postgraduates of opportunities other than research and development and industry should cash in on this by taking advantage of it. Not much is needed to persuade the Ph.D.s of today that the range of jobs they can do and enjoy is far greater than their predecessors have assumed. What universities are supplying is high quality manpower rather than the restricted description of chemists or Ph.D.s. A recent editorial sums it up as follows[6]:

'The sheer inability of many industrial companies to use Ph.D.s in non-research and development functions is beginning to change and the relative difficulty in finding sufficiently rewarding research posts should prove an incentive for candidates to consider applying themselves seriously to other functions, such as management, production and selling. In the long run their career structure will be different, but far more rewarding, and this must be of benefit, not only to the Ph.D. but to industry and the economy of the country.' From the same source a cognate clarion call is trumpeted by Duncan Davies[7]: 'The U.K. needs every single one of the Ph.D.s it is producing, as *people* (though it does not necessarily need the particular postgraduate training that we happen to have given them). The problem corresponds with that of the undernourished man who has lost his appetite. Large sectors of U.K. industry are inadequately led, planned and managed, and desperately need new blood; unfortunately, the Ph.D. who batters his way in there, may well have a daunting task ahead of him. Poor managers are far more resistant to change than are good ones, so that one has the paradox of stagnation where change would be more beneficial, and evolution and advance—beneficial enough—where things really aren't so bad. Over and above this, the Ph.D.s are needed in the schools, where sullen egalitarianism in the pay system usually interferes with the offer of a competitive salary to someone with an advanced degree. The Swann Committee has urgently recommended that this problem be tackled. Let it be said again and again: there is *no* U.K. overproduction of scientists, there is an under-awareness of the measures needed for their mobilization.'

One important aspect of the academic–industrial linkage, which is ripe for further development, is the chemical 're-treading' of industrial staff by chemistry departments. From this point of view, the currently extant system of postgraduate Advanced Courses (leading to an M.Sc.) has been little used. Only about ten per cent of the advanced course studentships offered by the S.R.C. are taken up by industry. This is understandable because of the difficulty of releasing key men for a full year. The provision of short courses with a credit accumulation system would be a partial solution and this is now under discussion. Even more important is the choice of schemes and we must have detailed advice and guidance from industry as to their needs in this respect. The loosening up of many universities' regulations now allow candidates in industry to present Ph.D.s on work done substantially outside the university and the arrangements provided by the Council for National Academic Awards have considerably broadened this scope. (The C.N.A.A. is a self-governing body set up by Royal Charter to award degrees and other qualifications comparable to those granted by universities, to students who complete approved courses of study or research in establishments which do not have the power to award their own degrees. It is the only organization in the U.K. which has the same powers as a university to award degrees.) Other methods of actively promoting joint industrial–academic Ph.D.s are also well in train[8], and further suggestions are not lacking[9].

Although I have been mainly concerned with academic motes, the industrial beams must not be swept under the carpet if a really fruitful conjunction is to be established. In particular, universities would plead with industry

for a detailed brief on their specific needs, instead of the airy vaguenesses which are too often produced. Forecasting of staff needs at a comparatively long range would also be useful (although industry is naturally terrified of being held to such postulated figures). Of all the sciences, it is generally agreed that chemistry already has the closest academic–industrial linkages. One healthy facet of this relationship is that neither partner treats the other with over-exaggerated respect. Mere slanging matches are by definition sterile, but it is surely up to both sides to ensure that the reciprocal comment is not only forceful but fruitful.

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DISCUSSION

G. A. Olah (*Case Western Reserve University, Cleveland*)—In my view, the quality of our Ph.D.s of today is higher than at any previous time. On the other hand it could rightly be questioned, whether we are producing too many Ph.D.s. The industrial need for chemists is clearly not limited to research Ph.D.s. Whereas good research scientists are needed and will be needed in industrial research laboratories, many other types of chemists are also needed. In many instances a B.Sc. in chemistry or chemical engineering followed by a postgraduate degree in Business Administration would prepare a young man better for a particular industrial career than a Ph.D. in chemistry.

E. S. Stern (*I.C.I. Ltd. Petrochemical and Polymer Laboratory*)—Three points in Professor Raphael's lecture seem to me to be of sufficiently wide interest to an audience of educationalists to deserve some comment from a member of industry.

(a) The induction of the B.Sc. into professional life is not the *sole* prerogative of the university research supervisor; all graduating students undergo a similar experience on entering a new walk of life. First bewilderment, then guided re-orientation. Unless great care is taken the student is, in effect, 'brain-washed' into considerable and undesirable dependence on his guide. As a result of the re-orientation, Ph.D. graduates are very different from B.Sc.s; but after three years, so are analogous men who have not proceeded to a Ph.D. very different, because they have during this period adjusted to whatever environment they have chosen. Learning and maturing are not processes that stop when a young man leaves the university.

(b) The postgraduate research training discussed by Professor Raphael and widely practised—at different levels of success—may well be too preoccupied with scientific content; the Ph.D. student is taught more chemistry, more experimental techniques, more about the directly relevant mathematical and physical tools. Little, if any, attention is paid to social environment or effects, but the course is beginning to look as cramped as the undergraduate course. In contrast to these instructional activities the acquisition of research techniques—the essentials of problem posing and problem solving—is entirely experimental. I am sure experimental learning is the most valuable way of making progress in research, but it is not systematically—or even overtly—monitored; in some places even the concept goes by default. There is a real need here to differentiate between 'content' and 'process' and make the student aware of his purpose—and of what he has learned and the applicability of what he has learned.

(c) The costs of Ph.D. training to their universities are, in fact, large. In the U.K. more than 3 000 man-years are spent annually by Ph.D. students. The costs can be calculated in a variety of ways. In industry, the costs of 3 000 man-years would be of the order of £25m to £35m; the direct cost in universities is, of course, much less, but the total cost must include the cost to the community of the loss of earnings by these men and particularly the loss of the scientific/technological contribution these men (the *elite* of their age group) could have made to the wealth-generating sector, i.e. to industry. It is this cost which has to be recovered, and more than recovered, over the *active* life of the Ph.D. *practising as a scientist.* This period of active scientific life may be as short as two or three years and for five out of six men is less than seven years.

J. W. Linnett (*University of Cambridge*)—The survey to which reference has been made by Professor Raphael is that carried out in the U.K. by the Committee of Heads of University Chemistry Departments, which has been in existence for about three years. A summary of the results has been published in *Chemistry in Britain.* It covered all the University Chemistry Departments in the U.K. except one and a very high proportion of all students were traced. So it does represent a very full coverage of the young people involved.

Now we have been told that the products of our Ph.D. courses in the U.K. are narrow-minded and have been narrowly trained. I am sure that there is some justification for this criticism. I am also convinced from conversations I have had that this is a problem in other countries also. It is a danger that we who are responsible for training research students must watch all the time. We must make clear to the student the disadvantages of becoming narrow-minded and do all we can to enable him to combat it. It is no good our complaining of their narrowness if we do nothing about it; I fear this is what we sometimes do.

We in universities are compelled to ask ourselves, what do we do for our Ph.D. students in the three or four years they spend with us that they could not get by three years research in industry. I sincerely believe that they do get something out of studying a problem thoroughly in depth for a fairly long period. This would not usually be possible in industry. Also in the university the man performs all the measurements connected with his research; he

services his own research. This is not the common practice in industry where the research is often serviced by technicians and by other groups. Later on in industry, because he has had this breadth in the university, he will be more effective. He has had the experience that will enable him to appreciate and judge better the help that is being given him by other groups.

I have much sympathy with the system common in continental Europe which includes a research problem of not inconsiderable size in the undergraduate course. This means that the young man has not only learned chemistry but has done chemistry during his undergraduate course. If there is no such content the situation often exists that the only way a student can get experience of research is by doing a Ph.D. At Oxford, England, the fourth year of the undergraduate course is completely devoted to research. I believe we would gain by having a variety of research training programmes of differing lengths to suit different needs. We, in the U.K., have an M.Sc. by research, taking one or two years but it does not carry with it the value of the Ph.D. in relation to obtaining a job. Consequently, it does not really constitute an alternative to the Ph.D. for those who want a shorter research experience, but definitely want some such experience. I think we must investigate ways of obtaining various levels of experience of university research. It is difficult to see how this can be done because of the 'halo' that is now associated with the Ph.D. I sometimes think that it is most unfortunate that we have developed the habit of addressing those who have obtained Ph.D.s as Dr X. It has given to this title what seems to me to be an excessive importance. However, I fear that it has happened and that we cannot now retrace our steps.

H. Zollinger (*ETH—Zürich*)—Research activities and education at the graduate and post-doctoral level are, in my opinion (but apparently in contrast to Dr E. S. Stern's opinion) over a long range useful also for industry. A specific example is the industry of synthetic organic dyestuffs. The fact that the British dyestuff industry was very successful in the last 10 to 15 years is because basic research in this and closely related fields has a high standard at British universities. Similar relationships between success of industrial research and research at universities can be found also in other countries.

G. S. Hammond (*California Institute of Technology, Pasadena*)—The fundamental differences between industrial and academic research are rarely recognized. The most legitimate objective of academic research is to obtain results which have maximum general usefulness, because these are needed by the world of science. Ideally, the experiments designed to obtain these ends should be as simple as is compatible with achieving the goal. In industry the problems are generated by entirely different circumstances; consequently, style of work and goals must be different, but not of lower validity.

'Brainwashing' is real. It occurs in two ways, one legitimate and the other illegitimate. Students tend to realize that their research preceptors enjoy their work and they develop aspirations to emulate the action because it is an obviously rewarding experience. In addition, some professors systematically perpetuate the notion that science is a 'holy' mission and that

entering industry is a compromise of integrity. We need more direct confrontation between students and truly representative people from industry.

R. S. Nyholm (*University College, London, U.K.*)—I would like to invite participants to indicate what kind of balance they consider desirable in research training between nature of the project, percentage of time spent on it, number and type of lecture courses etc.

John C. Bailar Jr (*University of Illinois, Urbana*)—The question of how much coursework and how much research should be included in the Ph.D. programme was faced some years ago by the Committee on Professional Training of the American Chemical Society. The success of that Committee's work in upgrading chemical training at the undergraduate level led to attempts to define what should be included in the graduate programme. It soon became clear, however, that vastly different methods were proving to be highly successful; for example, the Department of Chemistry at the University of California at Berkeley required almost no coursework, whereas the University of Illinois required a year or a year and a half of such work. Yet the alumni of both universities were highly successful in their later careers.

A. S. Dreiding (*University of Zurich*)—Playing the devil's advocate I want to ask a few provocative questions. They are related to the problem mentioned by several speakers and characterized by the word 'brainwashing' of research students. The problem concerns the aspect of our university system which leads to such a strong dependence of the graduate student on his research adviser. It is claimed that this situation often leads the student into such directions as do not fill *his* future needs.

Few university professors do anything to eliminate this dependence, because the system forces the professor to use his research student for his personal bread and butter: the research student creates the professor's publications and thus advances the professor's reputation. Prizes and even direct financial rewards can accrue.

Should we not consider changing the system? Do we not require a dissertation to be the result of an independent piece of research? Should the professor always have a good conscience when he puts his name on a publication which resulted from a dissertation of a research student.

J. A. Campbell (*Harvey Mudd College, Claremont, Calif.*)—If the employers of from one third to two thirds of the students object to the training, should not the educational system seriously consider the detailed nature of the complaints?

At least three studies of correlation of success with college performance show only one profession correlating positively—this is not medicine, law, business or industry, but teaching, i.e. teachers tend to produce teachers.

Project 'Hindsight' in the U.S.A. under Dr Chalmers Sherwin, attempted about three years ago to identify the source of major advances in research suggested by the U.S. Department of Defence. The results indicated that project oriented support was much more productive than field oriented research.

H. F. Halliwell (*University of East Anglia, Norwich*)—Professor Raphael sketched undergraduates' learning experience as based on theories carefully rounded off and on facts selected to support or contradict them. This sketch of Ph.D. training was one of coping with 'untidy facts' and of learning that attractive trails may be false. The implication of his words was that the latter was more desirable.

I want to stress that whether the pattern is like this or not is a decision that lies entirely with those who devise undergraduate courses. If it is a clearly desired operational objective that students should be able to cope with the novel and to exercise judgement on the unexpected, such an attitude *could* be developed long before the end of the first degree stage if we wished.

R. A. Raphael (*University of Glasgow*)—Even the most heuristic approach to teaching must still have a pre-arranged conceptual framework to act as more or less invisible guidelines. In research the guidelines are self-made and are continually being reconstructed, bifurcated and even deliberately broken in an untidy and frequently illogical and intuitive manner. It is this element of fruitful randomness that distinguishes research.