NYHOLM MEMORIAL LECTURE*

Growth, Change, and Challenge

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1 Introduction

I have found myself approaching this lecture with feelings of both gladness and sadness. I am gladdened by the honour you do me by this further association with the name of Sir Ronald Nyholm, saddened that this particular honour should have become available in my time. My association with Ron Nyholm began nearly thirty years ago, and it was only a few years later, in 1950, that he kindly gave a first-year lecture course for me, while I was away on leave of absence. The discussions that arose out of this marked the beginning of a long period during which I was continually to appreciate his care for education and his energy and skill in its service.

The time will come when these lectures will fittingly commemorate Ron Nyholm's initiatives in chemical education, in that they will be given by those who have made contributions to an established discipline of chemical education. Not being in that situation I have asked myself what small contribution I might make in memory of Ron Nyholm. In thinking of one of his outstanding qualities, and I have in mind his ability to review complex matters, I thought I might make some attempt at a broad survey of the changes in chemical education that have occurred during the past ten or fifteen years, at both school and university levels, and to consider their relationship to one another, if I could find one. This then is what I plan to do, though with more than a little apprehension. I am apprehensive firstly because I do not have the skills of a professional educationist and secondly because we stand so close to these recent rapid changes that it is hardly possible to do more than guess even the outlines as history may eventually see them. I am even more apprehensive when I consider the risk I take. When I consider changes at school level there are many who know from direct experience far more about it than I do; when it comes to university level no one can really hope to know what his colleagues have been doing; and then there are many interesting changes in further education and in the polytechnics which I shall have to omit completely. My justification must be the hope that others may be provoked to do it better, and the belief that Ron Nyholm, while not being satisfied with a provisional review, would nevertheless have encouraged it.

The difficulty of the task is compounded by the complexity of educational

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developments in which we still find ourselves after a decade of rapid developments. One has only to list a few of the more prominent ones to recognise the complexity: the introduction of new syllabuses, new teaching materials and new assessment procedures; the move towards comprehensive education, talk of a common examination at 16+, the certificate of extended education, the emergence of the so-called new sixth form, discussion of N and F levels; the introduction of modular degree courses, the developments of the Open University, the growth of the work of the CNAA. It is a time of great potential for educational change and as in all times of genuine excitement there are dangers to be feared. Many see a danger that in the course of changes, academic standards will decline, whereas others see a danger that meeting the needs of an academic elite will distort education as it expands to meet the needs of the many. Some see a danger that artificial subject boundaries, which have grown up historically, will continue to restrain the development of genuine science education at school level, whereas others see a danger of losing what only the mastery of a discipline can give.

In this complexity I want to single out two factors which have been determining influences in shaping the situation in which we find ourselves in chemical education. The first is growth: the growth of educational opportunity and the growth of chemistry. The second is change: change in attitudes about the role of chemistry in education and change in attitudes within chemistry.

2 Growth of Chemistry

Consider the growth of chemistry first. *Chemical Abstracts* which was first published in 1907, had by 1937 accumulated its first million abstracts, and by 1955 the total had reached two million. A third million was added by 1963, the fourth million five years later and the fifth million three years after that. By 1975 there were nearly four hundred thousand abstracts in a single year. The growth of chemistry is not however simply an extension of the scale of operation. New areas of chemistry, new techniques, and new theoretical approaches are developed, new insights are gained, and there are new implications and applications to consider. My own particular interest, spectroscopy, was a comparatively small subject even at the time when I began research. During that period quite new branches have appeared and it happens that a number of them have so many applications that they have become familiarly known by their initials. Among them are microwave spectroscopy, n.m.r., e.s.r., n.q.r., laser Raman spectroscopy and photoelectron spectroscopy. Those whose research interests lie in different areas could point to far-reaching advances in theoretical chemistry, biosynthesis, organometallic chemistry, enzyme chemistry, transition-metal chemistry, study of the solid state, to mention enough examples simply to indicate the present breadth of chemical knowledge. Nor is it simply a matter of breadth, for the demands of chemistry today stretch from the use of highly abstract concepts, and precise mathematical formulations, to the exercise of judgement in areas where the patterns in knowledge are both large and complex. It is a distinctive feature of chemistry that it combines both intensive and extensive approaches, and the interaction between the two has contributed much to its rapid growth. The richness of modern chemistry has attractions for all of us, but it carries with it special problems for all who teach it. Professor Laidler has already set out the challenge in a lecture[1] aptly entitled 'Too much to know', and has indicated its magnitude in some opening remarks, in which he expresses the view that teaching science effectively is now an even more difficult task than doing good research. One of his proposals to meet the immense growth of knowledge is to provide the student with a small-scale map of the entire area, and also some very large-scale maps of small areas. I shall return to this later but I want now, on this challenge that comes from the enormous growth of scientific knowledge, to quote from Medawar[2] who writes in 'The Art of the Soluble':

> 'The ballast of factual information, so far from being just about to sink us, is growing daily less. The factual burden of a science varies inversely with its degree of maturity. As a science advances, particular facts are comprehended within, and therefore in a sense annihilated by, general statements of steadily increasing explanatory power and compass—whereupon the facts need no longer be known explicitly, *i.e.* spelled out and kept in mind. In all sciences we are being progressively relieved of the burden of singular instances, the tyranny of the particular. We need no longer record the fall of every apple.'

The question I am raising is whether, as educators, our rate of assimilation and condensation matches our rate of advance as researchers. Can we as chemists continue to restructure our subject, in terms of generalisations of increasing power and scope, and so reduce, or at any rate avoid increasing, the load to be carried?

3 Growth and Change in Educational Opportunity

Restructuring knowledge in response to the rapid growth of knowledge is a central theme I want to explore, but before pursuing this I must return to pick up the other thread of growth, the growth of educational opportunity. A key date for our purposes will be 1962, which saw both the beginning of some marked developments in the teaching of chemistry at school level, and the Robbins Committee in the middle of its discussions on higher education. If we start by taking a bearing for 1962, by looking back to 1938, we find in that year 4% of children aged 17 in Great Britain were still at school. By the 1950's the percentage had doubled and by the year 1962 had nearly doubled again, reaching 15% (12% being in school and 3% in technical colleges).[3] The consequences for chemistry were that during the decade 1952—62, the number of A level passes more than doubled and for O level the numbers increased even more rapidly. By 1962 the stage had been reached where the number of pupils taking O level chemistry had risen to more than 67,000.[4] A large number would take chemistry

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[1] K. J. Laidler, 'Too Much to Know', *J. Chem. Educ.*, 1974, **51**, 696.

[2] P. B. Medawar, 'The Art of the Soluble', Methuen, London, 1967, p. 114.

[3] Report of the Robbins Committee on Higher Education, Chapter III, HMSO, 1963.

[4] Statistics of Education, Part 2, HMSO, 1962.

no further and only a tiny proportion would become chemists. Understandably the Science Teachers' Associations were making a plea for a change in attitude towards the role of chemistry in school education. The new message rang out, in no uncertain way, in the opening sentence of the statement,[5] which they published in that year, on teaching chemistry:

> 'The justification for teaching chemistry in general education lies in the contribution it makes to general culture.'

This was not simply a plea for change, but a practical document devoted largely to outlining syllabuses, drawn up with the new aims in mind.

At university level the rapid expansion came later. Over the five-year period up to 1962 the percentage of the age group at university, after some expansion, appeared to have settled at approximately 4% (a very slight fall was in fact detectable over the period).[3] Yet by the time the Robbins Committee reported in October of the following year, middle-class opinion, and for that matter academic opinion, had shifted to accepting the idea of major university expansion. Two thirds of academics supported the growth of the university system recommended by the Robbins Committee.[6] The rapid expansion that followed saw the number of students graduating in chemistry, in the universities as a whole, reach 2700 by 1969, nearly double the figure for 1962. Since that time the number of students in higher education has continued to grow but there has been some decline in the number of chemistry students, the number of chemistry graduates for the universities as a whole falling to 2190 by 1974. Both changes have been the subject of much discussion and both have led to changes in attitudes. The former was followed by the beginning of discussions of what has been succinctly called education through chemistry and the latter has been accompanied by the introduction of a wider variety of courses containing chemistry.

4 Changes in Chemistry

The last of the factors influencing educational developments, that I want to look at before turning to the educational changes themselves is that of change of attitudes within chemistry. Perhaps the most obvious single change in the development of chemistry during the past ten or fifteen years has been the growth of instrumentation, which has become so widespread in its applications that the methods are known almost everywhere in terms of abbreviations: mass spec., *X*-ray, i.r., u.v., and g.l.c. to add to the examples already quoted. However, the growth of instrumentation, complex though it may be, serves to change the methods of chemistry but does not of itself directly change the character of chemical thought. The striking feature here has been the development of increasingly sophisticated molecular and electronic theory, and it may be noted in passing that much of the new instrumentation leads in fact to structural

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[5] 'Science and Education. Chemistry for Grammar Schools'. A Report issued by the Science Masters Association and the Association of Women Science Teachers, John Murray, 1962.

[6] A. H. Halsey and M. A. Trow, 'The British Academics', Chapter 11, Faber and Faber, London, 1971.

information at the molecular level. Almost all chemical phenomena are now discussed in terms of the structures or properties of atoms, molecules or crystals, and such theories have become the spring-board for further advance in chemical understanding. In some areas the theory has become increasingly mathematical, but quite generally throughout inorganic and organic chemistry, there is now almost everywhere qualitative, if not quantitative, interpretation of phenomena in terms of molecular and electronic theories. Notable examples are the use of mechanistic ideas and orbital theories. The advance and refinements of mechanistic ideas have led to subtleties in their application that were hardly imaginable a decade or so ago, and a continual elaboration of orbital theories is now occurring in widely different areas of chemistry. The growth of theoretical understanding, and the favourable position which such theories now occupy, influence the way research papers are written and the way textbooks approach their subject matter and affect chemical education at all levels. The status accorded to molecular theory, in general, and electronic theories in particular, has come about for several reasons. It partly reflects the increasing maturity of the subject, partly it is a reaction against the factual load an earlier generation of chemists was expected to acquire as students, and partly it has come about through the prestige that quantum mechanics enjoys because of the immense power it is believed to have, in principle, if not yet in practice. Whatever the factors are that underlie the present standing of molecular and electronic theories, present attitudes towards these theories have had a strong influence on chemical education.

5 Changes at School Level

Bearing in mind the main themes, which I have attempted to sketch, I want to turn to consider the changes themselves, first at school and then at university. Looking back on what has happened at the secondary level we can see that three major changes have been going on simultaneously. Understanding these changes hinges on the recognition that the term 'chemistry' has come to have two meanings. One refers to a body of knowledge and the other to an activity. The first we can take to be epitomised by the textbook: systematic, ordered, and often sequential. The second involves quite different qualities: search, speculation, and testing ideas. The first of the important changes at school level has been a restructuring of the body of knowledge, and the second has been a considerable readjustment of view about the relative role of the two aspects of chemistry in chemical education.

I will come to the third change after pursuing the first two in a little more detail. The development of a topic in a textbook is very different from the actual way in which that topic developed. The imaginative steps, the testing of suggestions, the struggle to clarify ideas, the hesitant steps forward, and the breakthrough are largely lost and instead there is a clear systematic development of the subject. It is the systematisation that makes the textbook an effective way of communicating knowledge, but it is achieved at the expense of losing a sense of chemistry as an activity. There is a loss of both the history of developments and an appreciation of the ways in which science is advanced. (In passing, it may be noted that in the changes there was some swing away from the textbook, though there are now indications of some reverse in this attitude.) Discussions on the problem of meeting both objectives, an understanding of the body of knowledge and an understanding of science as process, can be traced far back in the history of science education.[7] An important step in the recent shift in attitude was the publication of those statements, already referred to, by the Science Teachers' Associations which expressed dissatisfaction with existing syllabuses and examinations and put forward proposals for change.[8] These discussions triggered off a number of developments, and among them was a move by the University of London, School Examinations Council. At the instigation of Ron Nyholm, the Council set up a panel to make an appraisal of its syllabuses and examinations. In brief, the reports of the panel stressed that the syllabuses were largely concerned with detailed specification of the body of knowledge, and that the examinations put strong emphasis on recall.[9] One of the members of the panel commented that parts of the syllabus read like a chemical seed catalogue. Subsequently changes were introduced in the syllabuses and examination for both O and A level.[10] I do not single out the University of London for special comment, but give it as an example which happens to be familiar to me. Its syllabuses and examinations were probably not untypical, and other Examination Boards have also made reappraisals.

The many changes which followed the publications on science education by the Teachers' Associations (now amalgamated into the Association for Science Education) occurred at a rate which must have surprised even the strongest advocates of change. Looking back, we can now see the developments as part of a tide of change in science education which was international. In the United States two chemistry projects were set up by the National Science Foundation: Chem Study and the Chemical Bond Approach. In the United Kingdom the Nuffield Foundation sponsored projects to develop new science teaching schemes, while in Scotland new teaching programmes[11] were developed by the Scottish Education Department. The development of the Nuffield schemes drew on the experience of a large number of people.[12] It involved hundreds of teachers in providing information about experimental work, and feed-back generally, in the school trials programme, as well as thousands of pupils who took part in the trials. Printed versions of the O level materials appeared in the period 1966—68 and those for A level in 1970—72. The O level materials have since been revised, and the revised materials are being published at the present time. At the same

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[7] D. Layton, 'Science for the People: the Origins of the School Science Curriculum in England'. George Allen and Unwin, London, 1973.

[8] 'Science and Education'. A Policy Statement issued by the Science Masters' Association and the Association of Women Science Teachers, John Murray, 1962.

[9] An Appraisal of the G.C.E. Examinations in Chemistry of the University of London, University of London, 1964.

[10] Report on Conference of Chemistry Teachers, University of London, 1969.

[11] Scottish Education Department, Circular No. 512, 1962.

[12] C. A. Coulson, *Chem. Soc. Rev.*, 1972, **11**, 495.

time as these developments were taking place many teachers were also contributing to a wide revision of syllabuses of Examination Boards. The body of knowledge demanded by the older syllabuses, and met by the textbooks, was frequently structured on the basis of nineteenth century chemical theory, using such foundations as the Laws of Constant and Multiple Proportions and the framework established by Gay Lussac, Avogadro, and Cannizaro. By contrast, revised schemes have been developed in which atoms, molecules, and ions are introduced essentially in an axiomatic way. The justification of the atomic theory is seen not as a result of a particular line of argument, but in terms of the wealth of interpretation it offers and the way of thinking it opens up.

In this outline which I am attempting to draw, the restructuring of the body of knowledge in terms of atomic and molecular theory is the first of the major changes. The second is the increased emphasis on chemistry as an activity, on making investigations, and tackling problems scientifically. The third feature is the integration of the two aspects of science. In many ways this is the most difficult aim to achieve. Those who practise in any area of chemistry have a large body of knowledge and particular skills in an activity. When a student is involved in some investigation, which is related to his own body of knowledge and skills in the same kind of way, then he is learning to operate as the chemist does. But if the aim of the investigation is to lead him to recognise the need for new concepts then it is a different situation. Here it appears as an educational technique. Any evaluation of attempts at integration will need to distinguish between these two different uses of the term. Finally, before leaving the school scene, mention must be made of changes in assessment. It has been strongly emphasised how important it was to make changes in assessment procedures to match the aims of the newer teaching schemes.[13] A good examination, it has been argued, is an extension of good teaching and should share the same objectives.[14]

In summary, at school level we have seen a redrawing of the map and a new emphasis on seeing something of the way in which the map is made. Partly it has come about in response to the growth of the map and the possibility of viewing it in a new way, and partly because reading the map, and discovering something of how it is drawn, are seen as serving broader needs of young people than before.

6 Changes at University Level

I want now to turn to changes at university level. Any attempt to make comparison with changes at school level must bear in mind the different ways in which schools and universities respond to social change. Like schools, universities experience the tensions and pressures of society, but are buffered from them to a much greater extent, for two reasons. First they have, or have had. considerable autonomy because of their method of finance. Secondly, although they now serve a range of needs in society, they have a strong sense of continuity

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[13] H. F. Halliwell, *Roy. Inst. Chem. Rev.*, 1968, **1**, 205 and *Chem. Soc. Rev.*, 1974, **3**, 373.

[14] J. C. Matthews, 'The Effect of Examinations in Determining the Chemistry Curriculum up to the Level of University Entrance', I.U.P.A.C., 1965.

of purpose which affects their response to social change. They have had a continuing role in the pursuit of learning that has repeatedly been re-affirmed, never perhaps more elegantly than by A. E. Housman in his introductory lecture at University College, London, in 1892, in which we find:[15]

> 'The faculty of learning is ours that we may find in its exercise that delight which arises from the unimpeded activity of any energy in the groove nature meant it to run in. Let a man acquire knowledge not for this or that external and incidental good which may chance to result from it, but for itself; not because it is useful or ornamental, but because it is knowledge, and therefore good for man to acquire.'

For a recent restatement[16] of this view of the role of universities we have:

> 'Their limited function is to remain dedicated to an activity which has already proved to be of incalculable benefit to mankind, namely the exercise of reason and imagination upon intellectual problems. This is their essential contribution to society and they should be implacably opposed to pressures to deflect them from this function.'

While this sense of permanence of purpose of the universities has a determining influence on their response to social change, it has not meant unchanging attitudes to teaching or curricula. Indeed a recent study[17] of developments in higher education, sponsored by the Nuffield Foundation, shows that curriculum change is more widespread than the generally conservative image of higher education would imply. Among the main changes found in this survey, which was widespread and not confined to chemistry, were the development of degree courses of greater breadth, the introduction of modular or unit courses, the development of a variety of independent learning schemes, a remarkable growth of project work and the use of a wide variety of methods of assessment. As might be expected from the measure of autonomy that universities enjoy, the changes have been varied, individual and *ad hoc*. To this extent it is unlike the school situation where one can point to systematic trends. At school level social pressures, operating through the growth of numbers, and the drive towards greater equality of opportunity have been a major influence on educational change. On the other hand, the growth of knowledge and chemical understanding has imposed greater problems in higher education. All important advances exert pressure initially for a place in the final year teaching programme, from where the pressure is transmitted to second- and first-year courses. Undoubtedly the main way in which this problem is being met is through the restructuring of chemistry, which at university level occurs quite gradually, unlike school level where it has occurred as a quantum jump associated with syllabus revision. Viewed from outside, the changes at school level may appear over rapid, while

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[15] A. E. Housman, Introductory Lecture at University College London, 1892, in 'A. E. Housman, Selected Prose', p. 18, ed. J. Carter, Cambridge University Press, London, 1961.

[16] Lord Ashby and M. Anderson, 'The Rise of the Student Estate in Britain', Macmillan, London, 1970, p. 151.

[17] 'The Drift of Change', an interim Report of the Group for Research and Innovation in Higher Education, The Nuffield Foundation, 1975.

those at university level may easily be overlooked. Yet because the changes at university level are occurring continuously, the effect can be far-reaching over a period of time. Many topics which were postgraduate studies or still beyond the frontiers of science, in my own time as a student, have moved into undergraduate teaching, and some have become central themes in the major restructuring of chemical knowledge that has taken place. At that time quantum mechanics was in transition from postgraduate to undergraduate studies, statistical mechanics was clearly postgraduate, mechanistic ideas had not made any significant impact on teaching of organic chemistry, the influence of ligand-field theory was a long way in the future. Today, to take a striking example first, we have reached a position where structure, mechanism, and orbitals are being introduced in some courses in an essentially axiomatic way. Some introductory account may seek to make them plausible but frequently it does not aim to consider at all rigorously, at that stage, how they may be determined. The justification for their introduction rests in their power to correlate chemical knowledge. Some very general examples of restructuring are the early introduction of quantum mechanics and thermodynamics and then the application of results in other areas. There are many examples in particular areas, such as the early introduction of ideas on chemical bonding, of general stereochemical principles, and quite recently even the early introduction of group theory.

Restructuring is always a difficult task, and because of the rate of growth of knowledge it is becoming increasingly difficult. It makes demands on scholarship just as the discovery of new knowledge does. But there is an important difference. Scholarship exercised in the advance of knowledge is widely held in high esteem. Understandably research draws adherents both because of the fascination it offers and because of the status it confers. The range of those pursuing research now runs from those for whom it is highly rewarding, to those for whom it may even be a burden. It is a situation which invites speculation on what might be the effect of better recognition of the exercise of scholarship, quite generally, in gaining a better understanding and better communication of our continually advancing knowledge. If we are serious about recognising scholarship here, it is not simply a question of individual institutions paying attention to contributions in this area. It is also a question of developing esteem for such contributions to scholarship both nationally and internationally, and of gaining some share in the prestige that is clearly attached to advancing knowledge.

Important as restructuring is, it would be misleading to suppose it is the only way in which the problem raised by the growth of knowledge is being tackled, though it would be the easiest to overlook. Another important contribution has been the introduction of modular or unit course schemes, such as that introduced by the University of London in 1966, which allows not only a wide variety of combinations of units in a degree course, but also allows those whose degree course is essentially in a single subject to have a choice of specialisation in the final year.

In summary, at university level we are faced with the problem of continually redrawing the map to meet the rapid growth of knowledge. Some help can be found by providing opportunity for choice among large-scale maps of selected areas. However, even if we are successful in this we are still left with a problem, to be discussed further, namely that redrawing the map means a loss of the history of how the map developed, and at the same time the redrawing obscures the very ways in which the map is extended.

7 Developments in Chemical Education

There are many contributions to change which can be mentioned only briefly. Among important developments not mentioned so far, which have potential for wider application are the increasing use of educational technology, including computer-assisted learning, and the experience of the Open University in designing and developing courses by groups working in a highly self-critical manner.[18] There has also been a wider emphasis on statements of aims and objectives, and the subsequent development of courses with the achievement of these in mind. Many have found the approach a salutary one, although it is still sometimes viewed with misgivings. Of course it can be pressed too far; an education which is open-ended clearly cannot be completely specified in behavioural terms. The complete achievement of a full specification of objectives would close the subject at that level, and the mind also. However, this is a danger probably seldom encountered at present. While many important developments have to be omitted entirely from a review in a limited space, no review today could neglect some reference to the growing provision for work in chemical education in polytechnics and universities, not only in colleges and departments of education, but also in chemistry departments. Such groups are making important contributions to developments in teaching and learning chemistry, at both secondary and tertiary levels. At the same time we are seeing the beginning of research in chemical education. To open up a new field of research is an arduous undertaking in any area, but those involved in this one are subject to strong and unusual influences. In the first place those who teach chemistry are often critical of educational research, having some suspicion of its methods, and arguing variously that its outcome is too removed from actual teaching to have much application, or that it was known already to good teachers. Even more important than this influence on the development of research in chemical education is the effect of the immense prestige of research in chemistry itself. It would be an unfortunate consequence if research in chemical education became dominated by a naive positivist approach, emphasising the quantifiable and the measurable. In any case, research in chemistry can afford to be neutral, but research in education carries with it the notion of improvement. This is not to deny the need for long-term fundamental research, not having immediate application, nor is it to put emphasis on development work. Underlying both of these, the notion of improvement implies the need to develop better understanding of chemistry itself, how it is structured and how it is being restructured, for these are inextricably bound up with gaining better methods of passing on that understanding. It

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[18] Open University Science Foundation Course, Open University Press, 1971.

means an awareness of, and some involvement in, restructuring of chemistry at all levels.

We can expect important benefits to flow from discovering better ways of teaching and learning how to read the map, through the use of empirical research techniques. At the same time there is the need for involvement in the redrawing of the map, for without this we shall be in danger of simply developing better ways of getting along old roads.

8 Present Challenges at School Level

I have argued that two factors, growth and change, have increasingly caused us to examine the content and structure of chemistry courses at all levels. I want now to turn to consider some of the present challenges, first at school level and then at university level. Central to the restructuring that has taken place, at both O and A levels, has been molecular and electronic theory, which accurately reflects attitudes of present-day chemistry. In an important way, this appears to be putting chemistry, at an introductory level, in a quite distinct position in science education. The chemist's approach of interpreting the world of the visible in terms of the invisible, particularly in quantitative terms, appears to make conceptual demands at early levels in education of a kind that neither physics nor biology call for at this level. Indeed it has been suggested from a recent study that a significant proportion of pupils have difficulties in handling the abstract notions involved.[19] There is clearly a direct challenge here to discover where this problem lies in relation to the teacher and the learner. Can alternative teaching approaches be developed, as experience increases, to achieve the same aims for a wider group of pupils, or does it mean that courses are needed that avoid this level of abstraction?

This is a problem specific to chemistry, but the growth of numbers raises more general problems at school level. G.C.E. examinations are seen on the one hand as the great defence of educational standards, and on the other as distorting school curricula. From the first point of view, the argument is that externally controlled examinations maintain high and uniform standards. From the second point of view, in its strongest form, the argument points to a pyramidal educational structure, having O level and C.S.E. at its base and the universities at the apex with a strong element of hierarchical control. As the base has increased there are more and more candidates for whom an examination, at some level in the pyramid, marks the end of the study of chemistry, and there has been increasing dissatisfaction with the system. The question is being raised whether school science education can still be based on an approach which is, or has been thought to be, appropriate for those who go on to the next stage. Put more forcefully by its proponents the question becomes: 'why should selection procedures for the minority determine the education of the majority?' The plea is being made to be freed of preparing all for what comes next for some. The way should then be clear, it is argued, to meet the present needs of the particular age

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[19] R. B. Ingle and M. Shayer, *Educ. in Chem.*, 1971, **8**, 182.

group, rather than concentrating on providing for the future needs of the minority. The teaching of chemistry, or perhaps science without differentiation into subjects for the younger age groups, could then be related more closely to the society in which we live. Such courses would put new emphasis on the applications and implications of science. On the other hand, questions are raised about the feasibility of such courses and the maintenance of educational standards. The central challenge that is being raised here is that of finding how to provide for the educational needs of the whole group and at the same time to ensure that the intellectually gifted in science are full extended.

9 Chemistry and Society

A number of schemes have been planned, or are already operating, which are designed to relate science more closely to society. A major aim is to put emphasis on social implications and technological applications. Attempts are being made to develop schemes at various levels, in which social aspects are woven more strongly into the course. More difficult to achieve is helping a pupil gain a basis, from which he or she can begin to develop some understanding of the contribution of science in our culture. The design of such courses presents challenging problems, particularly if they are to cater for a wide range of pupils, including the intellectually most able, among whom some will not be going further in science. Much valuable discussion is going on about the content of such courses at the present time. However, it may be that a significant part of the answer to the problem is not to be found by considerations of content alone. On the contrary it may be important to recognise that, for all levels of education, most will probably forget most of the chemistry they learn, for this raises the question of what should determine content in an acute form. I have recently had cause to discover that I have myself forgotten almost all that I once learned about terpenes. Only a little painful reflection is necessary to bring me to confess that it is not an isolated example. Were those who chose the content of these courses and taught me terpene chemistry wasting my time and theirs? Let me make it clear straightaway that I regarded those lectures on terpenes as brilliant and that I was held fascinated by them.

The question becomes this: recognising that many who study chemistry to a particular level will forget much of it, what educational outcome do we seek? There can be an important argument that even the forgotten material had a particular value in transforming the mind. Then there is the importance of the residual knowledge, about which we clearly need to know much more. But I want to fix attention on a third feature, namely attitudes which have been developed and remain even when much of the course content does not. If some of the newer courses at school level have been successful they will have developed, more widely than before, an attitude of tackling problems scientifically. Students will respond to new situations with an attitude of seeking to find out, and this attitude will survive after much of the content in which it was initially developed has been forgotten. The development of such an attitude represents a major change in science education, yet this attitude can be seen to a considerable extent as an academic attitude, stemming from a spirit of enquiry in the pursuit of understanding. If courses are to be developed, which relate science more strongly to the present experience and subsequent development of pupils within our society, there will be a need not only for changes of content but also the development of a broader range of attitudes. In these terms, teaching chemistry in a way that relates to the society in which we live calls not so much for finding a way to get the latest detergent into the course content, but for finding ways to develop attitudes which can later find expression and further development in social and cultural issues. Such attitudes would evidently involve doing, making, using, controlling and linking as well as finding out. All this calls for much more than syllabus revision, and it raises the question as to whether the depth of experience and breadth of examples exist to implement such courses at all widely, even if they are designed by those who do have the expertise. Certainly this was not what happened in developments at O and A level in the past decade. These developments, in fact, gave expression to a great volume of experience and examples of the kind of teaching they aimed to foster.

In summary, a lot of experience has accumulated on mapping the internal connections of chemistry but there is much less experience in mapping the external connections of chemistry. In this situation we are led overwhelmingly to one conclusion: we should keep open the possibility of exploring different ways forward.

10 Challenge at University Level

Turning to the position at university level, I do not think there can be any question that, with notable exceptions,[20] university departments have put emphasis on the body of knowledge, though there has been some shift of emphasis in recent years. Nevertheless, the main concern has been with what is essentially a consolidated body of knowledge, and the student is expected to acquire the art of operating within this consolidated, or nearly consolidated, body of knowledge. Since I have dwelt at length on restructuring a body of knowledge, it may well be asked how are these bodies of knowledge related? Paradoxically it is one and the same body of knowledge, and the resolution of the paradox is, that for the student coming to it for the first time the body of knowledge is essentially consolidated, but for the teacher it is gradually being restructured, in the light of new understanding as knowledge advances. Consolidation secures for the student order and systematisation but at the expense of a loss of both the history of how the subject developed, and a general appreciation of how science advances. Science as consolidation continually obscures science as process.

Tradition hands on the notion of chemist as researcher and innovator, but the actual emphasis in teaching is not on the exploratory but on learning the rules of the game as it is at present being played. Even problem solving is mainly of problems for which there are answers in the back of the book, or could be. For

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[20] See for example, C. Eaborn, *Chem. in Britain*, 1970, **6**, 330.

the most part they serve to develop and reinforce understanding of the rules of operation within the consolidated, or nearly consolidated body of knowledge, rather than develop powers of originality. Much that the student has to acquire is available in textbooks of one kind or another. Publications of original work or the great classics of chemistry play a minor role in his or her education. There is so much to know that the consolidation offered by the textbooks has great merit. Indeed it has been argued by Kuhn[21] that science education is characterised by textbook-type education, and he has gone so far as to argue that science education is probably more textbook oriented than that in any other subject, with the possible exception of orthodox theology. For training in operation at the level of what is consolidated, this is immensely effective. Some mitigation of the tendency comes about in indirect ways as, for example, through a lecturer's enthusiasm for his subject, or through informal contacts with staff and research workers. An important counterbalancing effect in recent years has been the increase in project work, but the experience a project can offer is necessarily limited and it cannot be expected to give insight into the great wealth of varieties of originality that has contributed to the advance of chemistry. For those who are going on to research it can be argued that the exploratory aspect of science can be left, but even here it is questionable whether it is the best route to a genuine science education. For those who do not take up research it raises the whole question of balance between gaining understanding of the present situation and an awareness of the ways in which chemistry has been advanced and is being advanced. If we are serious about what is increasingly being called education through chemistry we cannot avoid a reappraisal of the relative roles of these two aspects of science.

I have argued that acquiring a good understanding of the present state of the map is made difficult by the rapid growth of the map. Nevertheless, science education is in principle well developed to be effective for this purpose. It is in general much less well developed to communicate how new pathways have extended the map, how breakthroughs have been made and how pathways have become lost and have been replaced by roads which carry the great traffic of ideas so much more effectively.

11 Paradigms in Chemistry

The map analogy is inadequate to carry us further but the concept of paradigm developed by Kuhn appears to offer us a way forward. It is a notion that chemists can respond to with examples from their experience in learning, teaching, and practice of science:[22]

> 'It is, in the first place, a fundamental scientific achievement and one which includes both a theory and some exemplary applications to the results of experiment and observation. More important, it is an open-ended achieve-

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[21] T. S. Kuhn, 'The Structure of Scientific Revolutions', University of Chicago Press, 1970, 2nd edn., Chapter XIII.

[22] T. S. Kuhn, 'Scientific Paradigms', in 'The Sociology of Science', ed. B. Barnes, Penguin, London, 1972.

> ment, one which leaves all sorts of research still to be done. And, finally, it is an accepted achievement in the sense that it is received by a group whose members no longer try to rival it or to create alternatives for it. Instead, they attempt to extend and exploit it in a variety of ways. . . .'

An implication for science education appears to be that for some particular scientific activity there are concepts, principles, theory, examples and applications that constitute a unit which cannot be fully reduced to logically component parts which might function in its stead. The communication of such a unit is an art. To quote again from Kuhn:[23a]

> 'In learning a paradigm the scientist acquires theory, methods, and standards together, usually in an inextricable mixture.'

This view of the structure of science leads to the conclusion that the idea of localisation of scientific knowledge in theory and rules is an incorrect view of the cognitive content of science. In particular, such a view mistakes the role of problem solving in science education as supplying practice in what the student already knows. In the paradigmatic view of science, at the start and for some time after, the student doing problems is learning things about the physical world. In the absence of examples, the laws and theories would have little empirical content.[23b]

It may be that the successful identification of paradigms could take us forward to a better understanding of the structure of chemistry, and eventually lead to better ways of communicating it. It is tempting to speculate that if sets of paradigms could be identified and analysed then the distinction between the two aspects of science, the body of knowledge and the activity, might not arise in nearly so strong a form, and as a consequence a route might be found to circumvent some of the troublesome problems in science education that arise from the distinction. It could mean that problems about syllabus content or course coverage could be restated and clarified. New criteria might emerge for determining the most effective content to achieve a particular set of aims. A better understanding might be gained of restructuring, as old paradigms are replaced by new (just as research conducted within one paradigm is sometimes published within the context of another with a higher prestige value). At the same time it might also show more clearly how confusion can arise if the same scientific term is used in different or overlapping paradigms. 'Mechanism' may be such an example, belonging to two different paradigms, in one of which it represents a goal while in the other it is a starting point. The terms 'structure' and 'orbital' may provide somewhat similar examples. These are no more than speculations but the fact that this framework makes possible these speculations, at least suggests that there may be an avenue here to be explored.

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[23] T. S. Kuhn, 'The Structure of Scientific Revolutions', University of Chicago Press, 1970, 2nd edn., (*a*), p. 109; (*b*), p. 188.