NYHOLM LECTURE*

Conceptions, Misconceptions, and Alternative Frameworks in Chemical Education

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1 Introduction

In Britain, Australia, and many other countries, a very great deal of effort was devoted during the 1960s and the 1970s to developing new approaches to the teaching of chemistry in schools. Among the social influences that led to these efforts were the very great changes in chemistry itself, both as a discipline of knowledge and as a professional research and development field, that occurred in the years of post war recovery after 1945.

It is timely now to make a realistic appraisal of what has been achieved through these efforts and in doing so to try to define and contribute to some of the challenges that confront us in the 1980s in the field of chemical education.

In many countries, there do now exist much improved courses for educating *in* chemistry those pupils (about 20% of any school age group) from whom the future chemists and other science based professionals will come. With minor ups and downs in the supply of these professionals, the school systems (including those in many developing countries) are preparing this minority group of secondary age pupils with a quite reasonable efficiency. Indeed, in a number of countries as the economic conditions worsened in the 1970s, supply of this technical manpower resource overshot the demands, and problems of unemployment and under-employment of these skilled resources have occurred.

On the other hand, the last five to ten years in particular have provided enough evidence that the sorts of chemistry courses we have developed have not been adequate for the purpose of educating the rising masses of secondary school students. They remain inadequately literate in the physical sciences and they do not have a sense of personal satisfaction and useful achievement from their encounters in schools with the subject of chemistry. The hopes expressed earlier in the 1970s by some that these learners might be educated *through* chemistry have not been sustained whether the criteria are immediate interest, sustained interest, positive learning, sense of achievement, or awareness of the many roles of chemistry in society.

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Throughout the 1970s concerns about the inadequacy of school science (including chemistry) education were expressed internationally *via* a number of slogans – an important method of highlighting issues in education. The Social Relevance of Chemistry Curricula was questioned early in the 1970s. Chemistry (and other science) education in schools was then called on by the late 1970s to contribute to an appreciation of the interplay between Science and Society. Technology was added to this duo and S.S. and T. is now a contemporary slogan for the issue of a more meaningful chemistry education in schools. At a meeting of the chemical education division of I.U.P.A.C. in Maryland in 1981[1] a plenary session was held entitled *Tailoring Chemistry Curricula to Culture* – one more way of expressing the sense of inadequacy about the contemporary efforts in chemical education.

In the 1980s these concerns have crystallized in a number of places into formal acknowledgement of failure, and new policies have been established. In Britain, a Secondary Science Curriculum Review is under way.[2] In Scotland, new policies to develop curricular programmes based on the Munn and Dunning Reports are beginning. In the Asia Region of UNESCO (to which Australia belongs) one of the two top priority educational projects for the next five years, is entitled, *Science for All.* Throughout the British Commonwealth a new priority area is entitled, *Science Education in relation to the World of Work*–a somewhat euphemistic title for a concern that stems from the existence of high levels of unemployed young persons among the post school population in most of these countries.

A general question being asked in all of these stirrings and new beginnings can be phrased as follows:

(i) *Can chemistry, as a subject field, contribute to the schooling of the 80+% of learners in each age group who are most unlikely to study chemistry again after leaving school?*

In the light of the above evaluations of present chemistry courses, two broad approaches to this question can be considered. The first is to suggest that there may be quite radically different ways to define chemistry for schools so that it does make an effective contribution to this 80%. The second is to suggest that there may be new ways to communicate chemistry, however it is defined, so that the learning of it is much better by all learners than occurs at present. The latter approach would also have a direct relevance to a more subtle evaluation that contemporary research is beginning to provide of the present school courses. This relates to the level of understanding of chemistry, as distinct from the examination efficiency, that the more 'successful' 20% acquire as they are prepared for possible study of chemistry beyond school. It appears that criteria of 'understanding' are much less well met by a great deal of present chemical education than is commonly believed. This new evidence is coming from countries like Australia, Germany, Sweden, USA, Britain, and New Zealand where these aspects of chemical learning have so far been explored.

[1] I.U.P.A.C., 'Teaching Chemistry in a diverse world;. Proceedings Sixth International Conference on Chemical Education, University of Maryland, 1981.

[2] R. West, *Sch. Sci. Rev.* 1983, **64**, 407.

A second question is thus posed to chemical educators by this further type of evaluation of much chemical learning that is occurring in our schools with the 20% of learners who may go on with further chemical study.

(ii) *How can chemistry be taught for greater understanding?*

Answers to this second question would, of course, also be a contribution under the second approach suggested above to question (i).

Two fields of current research in chemical education contribute directly to the questions above and these will be drawn on in the two parts of this paper that follow. Both fields also involve conceptions, misconceptions, and alternative frameworks about chemical education.

2 Defining Chemical Curricula for Schools

Historical and sociological studies of the curricula of schooling began to gain prominence with the work in the 70s of persons like Bourdieu and Passeron[3] in France, and Young[4] in Britain. With respect to the fields like chemistry, Layton[5] illustrated from a study of some 19th century innovations in Britain how the curriculum for schools is shaped and constrained by a variety of competing social forces. Jenkins[6] and Waring[7] have carried out other analyses within this general approach as have Bailey[8] and Fensham[9] in Australia.

The basic starting point for this type of research is the recognition that chemistry teaching in schools does not take place in a social or political vacuum. School systems and schools themselves are established by societies to fulfil social purposes, and the explicit and implicit curricula of the school are both major instruments for these purposes. Some of these purposes are *political*, such as sorting out those who will move, from school, into certain positions of power and influence and those who will not. Some are *economic*, in that they relate to ensuring that appropriate numbers and sorts of adequately trained manpower become available from the schools to maintain and develop the national economy.

Chemistry as part of the total curriculum of schooling has and is serving both these purposes. It does sort out learners and it is an important ingredient in the preparation of a number of key technical groups in most economies. It has also been associated with another important social demand, namely, keeping the discipline of chemistry going and growing. Layton has referred to this purpose as '*subject maintenance*' and it is certainly from the ranks of the successful 20% that university chemistry departments draw their own students and in due course their future colleagues.

Figure 1 presents diagrammatically this societary view of the role of schools and

[3] P. Bourdieu and J.-C. Passeron, 'Reproduction in Education, Society and Culture', Sage, London, 1977.

[4] M. F. D. Young, 'Knowledge and Control', Macmillan, London, 1971.

[5] D. Layton, 'Science for the People', Allen and Unwin, London, 1973.

[6] E. W. Jenkins, 'From Armstrong to Nuffield', Murray, London, 1979.

[7] M. Waring, 'Social pressures and curriculum innovation', Methuen, London, 1979.

[8] R. F. Bailey, 'The decisions and control of Victorian curricula for chemistry, 1935–1975', M.Ed. thesis, Monash University, Clayton, Victoria, 1978.

[9] P. J. Fensham, *J. Curric. Stud.*, 1980, **12**, 189.

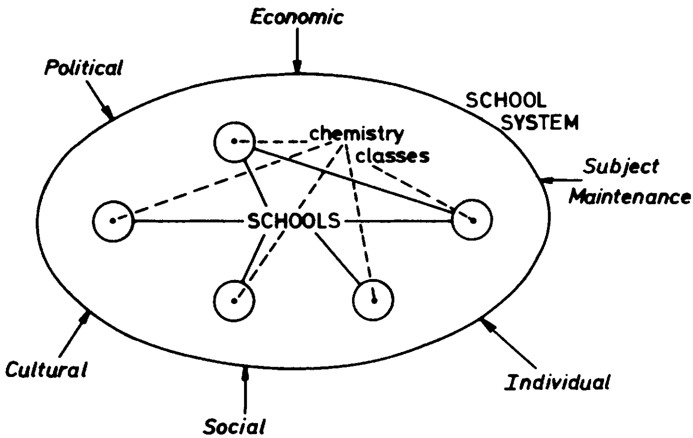

Figure 1 *The place of chemistry classes within schooling and the societary demands and constraints that affect their curricula*

of chemistry curricula in particular. The three social demands already mentioned are indicated in the top half of the diagram.

From the 1940s to the early 1960s when the first products of curriculum renewal began to be used in schools, these three were the primary (almost only) tasks for the teaching of chemistry in schools. Only about 20% of an age group participated in the full scope of secondary education in many countries (including Britain and Australia).

Chemistry teaching began with this group at or beyond 14 or 15 years of age, the compulsory age for schooling after which the majority of pupils left to enter the world of work. For many, it was the experience of employment that provided a second and more significant learning experience for adulthood than the school system had been able to achieve. Within the minority at school, chemistry was predominantly a field of study for boys who were, in any case, by the final years of the secondary school, a very clear majority of the remaining pupils.

From 1960 onwards, the complement of the secondary school began to change rapidly with many more of an age group (and hence a wider cross-section of the society) participating. By the 1980s, in Australia and Britain, more than 60% of the age group were in school at 16+, and 30 to 40% of the 17+ group were in their sixth year of secondary schooling. Nor are the figures for these countries unusual, for many developed as well as some developing countries exceed this level of participation in schooling. A feature of this increase has been the greater involvement of girls. In Australia for example, by the late 1970s girls formed the majority in the final year of secondary schooling. Since 1975 these much changed demands on the school have been further complicated by the high levels of unemployment in many countries, especially among youth between the ages of 15—20. In Britain and Australia there is now more than 20% unemployment in this age group and many more than this fraction will experience some periods of unemployment after the completion (whether with formal success or not) of schooling. Unemployment among this potential school age group is now as significant a fraction as the percentage who will move on, with success, from schooling into the varieties of higher education.

It is thus not surprising that schools and their curricula now face a number of other social demands. Among these are those we can call *cultural* since all these persons will live in societies and cultures that are inextricably influenced by and dependent upon the chemical and other sciences. Another *social* purpose stems from the need to have an informed populace who will support, or withhold support from, those developments that are possible because of technologies or products that are chemically based. Then there is always the purpose that relates to assisting *individuals* in all sorts of ways to share in and respond to the great human endeavours we associate with chemistry.

It is over the demands from these societary sources (see the lower part of Figure 1) that the concerns and admissions of failure of present chemistry curricula have largely arisen.

Chemistry curricula can and do change. It is instructive to examine them over

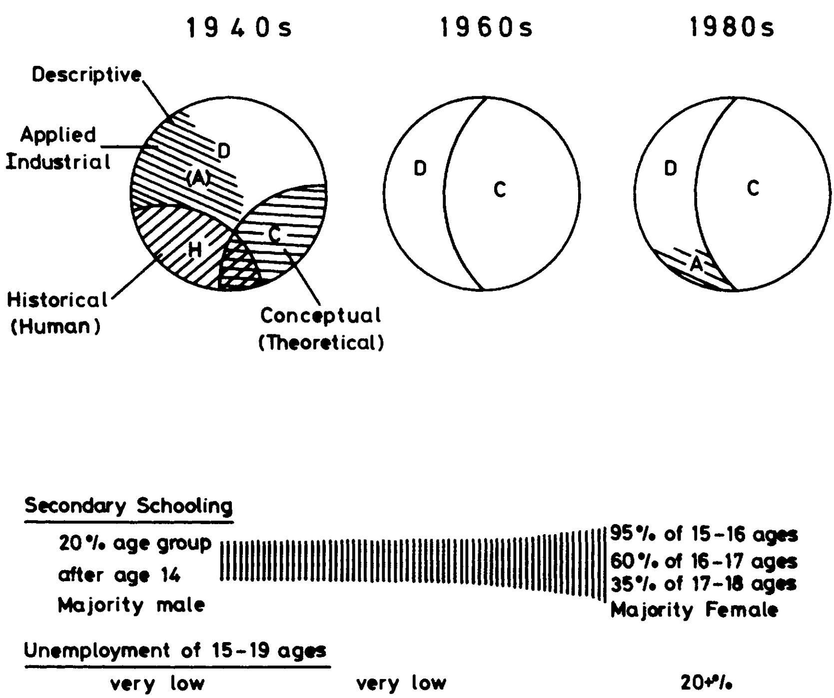

Figure 2 *Changes in the content of school chemistry 1940—1980 and some features of the secondary school age population*

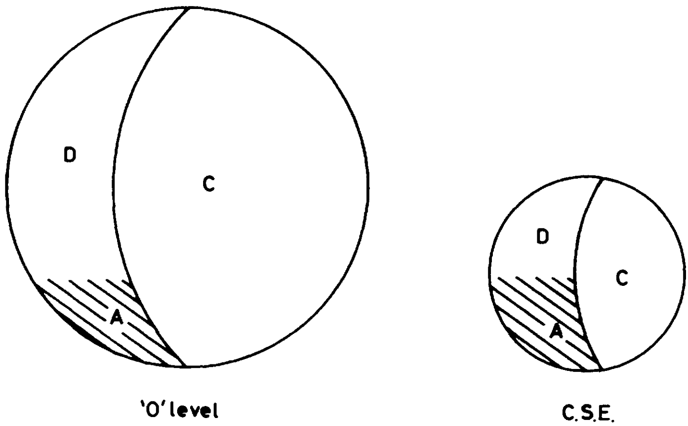

Figure 3 *Content analysis of examination questions for 'O' level and C.S.E. Chemistry 1980—81*

the time scales when the societary changes mentioned above have occurred. Content analysis is a method of classifying text books, course statements and examination papers so that the knowledge to be learnt in a subject field is classified into broad categories. It is important in applying this technique to distinguish between the rhetoric of a curriculum and those aspects of it that, in various ways, become perceived by teachers and learners alike as being the 'knowledge or learning of worth'.

An analysis of the chemistry courses in Australian schools reveals a significant change in the knowledge of worth from the 1940s to the new curricula of the later 1960s. Conceptual or theoretical aspects of chemistry moved from about one third of the content to about two thirds, displacing much descriptive or factual content (including almost all the details of industrial applications of chemistry and the considerable number of references to historical persons in the development of the subject's coverage of substances and explanatory ideas). Some further curricular reforms in the late 1970s did little to change the theoretical/descriptive proportion but did re-introduce some applications of chemistry. These analyses of content are shown diagrammatically in Figure 2 along with some data about the changing secondary school population.

A similar analysis has been made using the 'O' level and C.S.E. examination papers of the English examination boards for 1980 and 1981 as the source of 'knowledge of worth'. Some of the alternative papers which, as yet, are taken only by a small proportion of chemistry pupils in Britain are excluded. The results of this analysis (see Figure 3) indicate a not very dissimilar type of knowledge content in these two kinds of chemistry courses even though the C.S.E. curricula were intended to extend meaningful learning of chemistry from the 20th percentile to about the 50th percentile of the age range.

Few questions occur on the C.S.E. examinations that could not be asked on the

'O' level papers. The proportions of theoretical (C) and descriptive (D) knowledge are not very different although descriptive knowledge of chemical applications is more evident on the C.S.E. papers. There is no obvious block of questions on C.S.E. papers that relate chemical knowledge to social, economic, or political aspects of society. Nor do the common types of household or public chemicals emerge as the substances to be learnt about. There are, of course, a number of questions of both theoretical and descriptive chemistry on the 'O' level papers that do not occur on the C.S.E. papers, but they are extensions of the same sorts of knowledge rather than being representative of other sorts of learning such as historical origins of the subject, technological applications, or explorations of the manner of chemical reasoning from data to theory.

Another finding of these content analyses is the way the knowledge content is arranged for learning. By far the commonest arrangement in existing courses is as a sequence based on the development of a theoretical concept from its simplest or definitional form to more and more differentiated aspects of the same concept. This type of sequence is shown in Figure 4.

A typical example of this arrangement is the introduction of acids and bases, quickly followed by their abstract definitions, which leads into their differentiation into weak and strong by quantitative aspects of these types of substances, and then followed by their interactions, *etc.* Again, chemical equilibrium is introduced and pursued through a variety of widely (and bewilderingly to the learner) different sorts of chemical systems—gases, solution, precipitation, complex formation, redox, *etc.* These familiar and obvious sequences will be contrasted later in the paper with other arrangements. It will suffice at this point to note that they are characterized by increasing complexity, and by a sequence of learning that means each step is important if subsequent steps are to be learnt, and which has no obvious termination except as the particular course content for a given level determines. Furthermore, particular chemicals or reactions are merely exemplary for the conceptual learning and not the actual focus of the learning. For example,

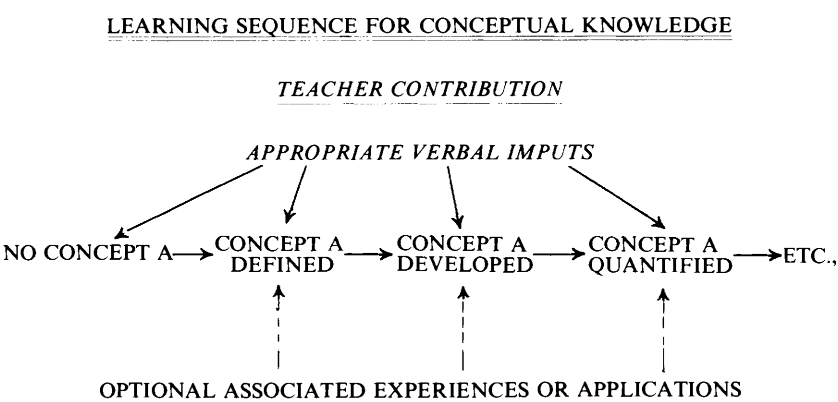

Figure 4 *The teaching/learning sequence for conceptual knowledge*

the reaction of hydrogen with iodine is commonly referred to in the sequence on equilibrium but the reaction with chlorine (an obvious analogue for many learners) is never discussed at this point.

In many courses there are recommendations that practical work should precede or follow these conceptual steps if possible and in some of the more recent courses applications of a conceptual step are quite often given in the texts or course outlines. However, there is a sense in which these are optional extras since the focus for the learning remains on the conceptual knowledge and does not move to the realities of the practical work or to the applications as chemical events in their own right.

It will, I believe, be evident that content for learning that is chosen and organized in the ways that emerge from these analyses have the following characteristics:

(i) It is predominantly related to the theoretical knowledge of chemistry.
(ii) It involves a sequential demand for conceptual learning without an obvious focus or terminal that has chemical reality.
(iii) It expects the learner to be motivated to the theoretical knowledge of the discipline of chemistry or by the fact that chemistry is a required subject for his/vocational goals.
(iv) It is preparatory for still more complex aspects in a later year of school, or in some course (such as university studies) that could follow schooling.

Such characteristics require a persistence of interest and intellectual achievement in learners that many are not likely to maintain. Courses of this type are, however, likely to fulfil the three upper social functions in Figure 1 that involve selection, preparation and a high status for academic or theoretical knowledge.

These sorts of analyses also indicate that during the 1970s, in both Britain and Australia, attempts were made to extend effective chemical learning to a much wider cross-section of secondary learners by using essentially similar, but reduced chemical content for learning. If these efforts are now part of the acknowledged failure that has been evidenced above, it is useful to summarize, as above, their characteristics since these will need to be avoided in any attempts to define alternative chemical education for the 80%, which is likely increasingly to include, as part of the population of secondary schooling (through legislation or financial incentives), those groups who at present make up the politically embarrassing youth unemployed.

If the success of present courses has been improvement of the education of a minority *in* chemistry, their failure is the education of the majority *through* essentially similar sorts of chemistry.

Using these characteristics of present chemistry courses it is possible to list another set of characteristics that could be an alternative basis for learning from chemistry.

One set of alternative characteristics for the content of the chemistry to be learnt could be:

(i) It should have as its foci aspects of chemistry other than the theoretical concepts.
(ii) It should have goals for learning that are obvious to (and in some cases determined by) the everyday lives of learners.

(iii) It should draw its motivation from the interests of the learners, that is, from chemistry's prospects of enhancing their mastery of the personal and social processes of living.
(iv) It should include knowledge content that contributes to the terminal learning goals and is not simply preparatory to some future learning in the subject.
(v) It should be capable of being learned in some sense by the majority of learners.

It will not, however, be sufficient to consider chemistry as a corpus of human endeavour and to devise programmes for chemical education that are consistent with these alternative characteristics. This is but one of the tasks that is needed, although it is the one appropriate to address in this paper.

The other task is the establishment of conditions of organisation and support within school and school systems, and of reward and understanding in the community so that such alternative contributions of chemical education become viable, attractive and effective. Pupils and their parents will need to perceive them as of personal worth, and employers and other community groups as having social worth. Many pupils among the 80% see little personal worth in present chemistry and their parents see only the extrinsic worth that achievement in chemistry keeps more doors open for employment possibilities. Present chemistry courses are perceived by employers as having vocational worth in some cases and more generally as of moral worth since they involve hard and demanding attitudes of study.

These socio-political tasks in relation to particular subject areas in the school curriculum will be a matter for each country and the appropriate conditions in one will not be transferable. It is, however, likely in all countries that the support of professional chemists, and in particular of powerful academic chemists in universities, will be necessary if these changes or alternative forms of chemical education are to gain acceptance and not be seen as of little worth in comparison with traditional courses. In the case of C.S.E. and 'O' level chemistry in England, to run these courses in parallel seems inevitably to restrict and downgrade the former, as well as not providing the 'O' level group with many aspects of chemistry from which they might also have gained benefit earlier in the secondary years.

Garforth[10] has succinctly stated one of the problems associated with the recognition of radically new conceptions of a field of learning drawn from the richness of chemistry.

> *'It may well be that there is a corpus of knowledge without which no syllabus could be called chemistry. Equally it may be that by our schooling, subsequent training and teaching we cannot see anything different adequately filling the space called chemistry at the school level'.*

The potential of chemistry as a science and as a field of human endeavour for education in schools is far greater than is at present being exploited. This is not difficult to show. If chemists of all types are asked to list the features of their subject—the objects, people, events, facts, and ideas which they recognize in their lives as chemists—it is not difficult to obtain a list that can only be described as

[10] F. Garforth, 'Chemistry to 16+ Examination', *Educ. Sci.*, 1983, No. 102, 29.

a very rich diverse conglomerate on which the word CHEMISTRY confers a common identity. It can only be represented by a multi-faceted collage of raw materials, processes and products, historical and contemporary persons, knowledge and numbers, commercial and research procedures, *etc., etc.*

Once this multi-faceted corpus, CHEMISTRY, is drawn up, it is possible to view it from a variety of frames of reference, which in a sense lead to transects of the corpus. One such transect might list the processes and procedures chemists use for their purpose. Another would emphasize social or industrial or personal products. Again, there is a transect that represents the historical development of the subject and the contributions of its historical persons. There are the transects of descriptive properties of substances and the conceptual knowledge used to describe, generalize, quantify, and explain.

These transects will constantly intersect each other and their junctions will focus on a substance, its properties, its uses, its descriptive origins and the persons of its past and present, *etc.*

The content of school chemistry has, as has been shown above, at different times recognized some different transects of this corpus of CHEMISTRY, but there has rarely been much of its richness evident in the knowledge of worth. The particular strengths for education of the intersecting transects are in most contemporary courses even reduced from what they were in the 1940s.

The chemical education of most recent developments for schools has been in a sense a journey along the surface formed by two dimensional transects (descriptive properties and theoretical concepts). It has been drawn and defined from *within* the corpus. Its limited two-dimensionality is reinforced by the representations of this sort of chemistry that make up the pages of a text-book, the sheets of examination papers or the words and symbols on blackboards so heavily used in chemistry teaching. When the education of the 80% is being considered, it is helpful to try to stay *outside* the corpus, viewing it from many angles, and selecting from it rather than becoming immersed in just some of its aspects.

Nelson[11,12] has made a valuable contribution to this type of consideration of chemistry by urging that the transects of pure and applied chemistry can and should be traversed together. If this is done, he argues, chemical education will also regain the contribution of the intuitive approaches that are so valuable to chemists but which have been overshadowed by rationality in present courses.

The 80% need to be educated *about* chemistry rather than in it. This does not mean at all that they should be taken on a quick and superficial tour of the surface of the corpus. Rather, it means that they are more likely to gain useful insights and knowledge about chemistry if they study in depth a few well chosen examples of its intersecting transects. In this sense the depth (compared with the breadth of conceptual coverage) of the chemical education of the 80% could be greater than for the 20% with their concentration on the theoretical. Later studies and experi-

[11] P. G. Nelson, 'What is Chemistry, that I may teach it?' Department of Chemistry, The University, Hull, 1981.

[12] P. G. Nelson, *Educ. Chem.*, 1983, **20**, 122.

ence in employment, of course, add a number of other aspects of chemistry to those of the 20% who do eventually become practising chemists.

How can such an approach to CHEMISTRY be used to define a chemical education that has the characteristics that may be appropriate for the 80%? Three possibilities will now be discussed to illustrate that there do appear to be good prospects for these alternative frameworks for a content of chemical education. In considering their merits the set of alternative characteristics is one sort of criterion to use. Another way of setting up criteria of worth is to list consistent learning outcomes that we know are not well achieved at present and desirable curricular experiences that also seem to be rather generally lacking. Table 1 lists some of these sorts of outcomes and experiences.

Table 1 *Some outcomes and experiences for more effective chemical education*

GOALS OF CHEMISTRY FOR ALL

EVERY STUDENT SHOULD BE ABLE

1. TO EXPLAIN A CHEMICALLY-BASED APPLICATION
2. TO EXPLAIN HOW THE SUBSTANCES OF EVERYDAY LIFE CAN BE REGARDED AS CHEMICALS
3. TO STATE (WITH RELEVANT DETAILS) THE SORTS OF PEOPLE WHO FIND EMPLOYMENT IN THE FIELD OF CHEMISTRY

EVERY STUDENT SHOULD HAVE

4. PRACTICE IN THE APPLICATION OF CHEMISTRY TO REAL (DOMESTIC, LEISURE, COMMUNITY, ETC) PROBLEMS
5. MEANINGFUL EXPERIENCES OF EACH OF THE MAJOR ACTIVITIES OF CHEMISTS
6. EXPERIENCE, WITH JOY AND EXCITEMENT, OF PHENOMENA THAT ATTRACT PEOPLE TO CHEMISTRY
7. SOME EXPERIENCE OF THE POWER OF CHEMICAL KNOWLEDGE.

A. Learning what Chemists do.—Chemists work with a great variety of chemicals and reacting systems. However, it seems that, beyond these specific details, chemistry is a relatively simple science in terms of the number of different activities that chemists do. In Table 2 there is a list of six of these essentially chemical 'doings'. It probably needs a few additions but groups of chemists considering it have not been able to double or treble it.

Each of these six has countless examples in research chemistry, in applied chemistry, and in the chemistry of living at home and in society. If we are prepared to put a focus on these activities it should not be difficult to enable every learner to have several meaningful examples of each type of doing. Such a content for chemical education could meet the alternative characteristics (i) to (iv) on pages 206 and 207 but what about (v)?

Table 2 *Essential activities or 'doings' that are characteristically chemical*

CHEMISTS' NAMES		*PRACTICAL EVERYDAY EXAMPLES*
PURIFICATION	SEPARATE	CLEANING CLOTHES
SYNTHESIS	MAKE	FIBRE GLASS PATCHING
ANALYSIS	IDENTIFY	DISTINGUISHING TURPENTINE FROM KEROSINE
STRUCTURAL STUDIES	FIND ALTERNATIVE	DETERGENTS
PROPERTY SEARCHING		CHOOSING MATERIALS
REACTION CONTROL	INHIBIT	STEMMING CORROSION
	FACILITATE	DEVELOPING A FILM

Some idea about how many may be able to learn some of these practical skills can be gained from considering their teaching/learning sequence in Figure 5.
The learning of practical skills has quite different stages for learning and instruction from those for conceptual learning in Figure 4. These differences are encouraging to the possibility of successful learning [alternative characteristic (v) on p.207] at least to the level of improved skill. Indeed, it is known that much more complicated but desirable practical skills, such as driving a car, are learnt to this level by very large proportions of the population.

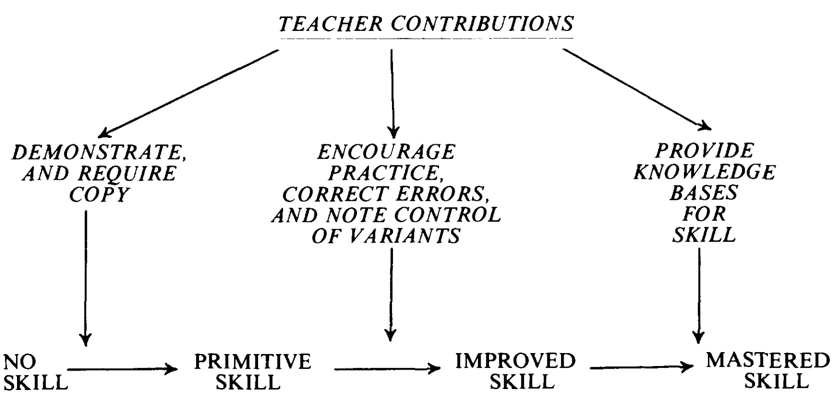

Figure 5 *Teaching/Learning sequence for practical skill acquisition*

B. Learning about Chemicals as the Substances of Everyday Life.—Gillespie,[13] Watts and Bayliss,[14] Cole, Watts, and Bucat,[15] and numerous others have all criticized modern courses for their neglect of chemicals as the primary content of chemical education. Some of the teachers of the Alchem course in Alberta have tried to discipline themselves to introduce chemical topics to their beginning learners only if they can physically show them the chemicals involved.

If it is the 80% with whom we are concerned, an emphasis on chemicals will need also to shift its focus, at least for a good deal of the time, from chemist's chemicals to the chemicals of everyday life.

In endeavouring to convince a class of 16 year olds of the power of chemical formulae for describing the composition of everyday substances, the author was confronted with more than one hundred different substances the pupils found from the contents data on the packets and bottles in their own kitchens and bathrooms. His reference books (quite reasonable compared with most teachers) provided the formulae for only fifteen of the substances. A British Pharmacopoeia and Mercks Index enabled formulae, properties, and uses of more than 90 to be reported back to the class. Most school teachers, at least in Australia, do not seem to have been introduced to these invaluable resources for everyday chemicals.

Consideration of the source of available chemicals provides an easy and potentially motivating content for a chemical education which is based on the chemistry of chemicals and which takes their social, economic and political realities seriously. At any time in history, the available chemicals in a country or region are either natural raw materials, manufactured locally, or imported. At another time, what falls into each category will have changed if new chemical skills are acquired and the other determining social conditions have also changed.

C. Learning about Chemical Applications.—Fehr[16], in the context of mathematics, pointed to a truism that would have profound effects if it was applied to chemical education:

The chemistry of an application is not the same as chemistry with applications.

The simplicity of this statement is beguiling, but its disturbing impact on our present practice is evident when the learning of an application (or a chemical technology) (see Figure 6) is compared with the learning of conceptual knowledge in Figure 4.

Learning a chemical application begins with experience of the application and this initial focus (or terminal) remains very visible as the various aspects of the application (around the circle in Figure 6) are considered in the learning experiences.

[13] R. J. Gillespie, *Chem. Aust.*, 1980, **47**, 499.

[14] D. W. Watts and N. S. Bayliss, 'Chemistry for Australian Schools', Australian Academy of Science Report No. 23, 1979.

[15] A. R. H. Cole, D. W. Watts, and R. B. Bucat, 'Chemical Properties and Reactions', Cole, Watts, and Bucat, Perth, 1981.

[16] H. F. Fehr, *Educ. Stud. Math.*, 1968, **1**, 347.

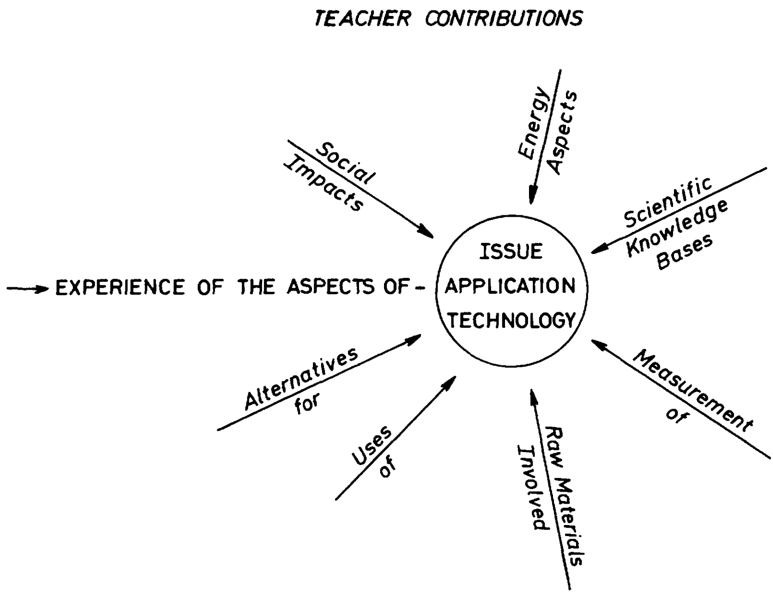

Figure 6 *A model for learning about a chemical issue, application, or technology*

In the case of conceptual learning the applications are simply references from the primary learning focus which is progression along the conceptual sequence.

When an application from the corpus of chemistry is taken, the knowledge on which it is based immediately will be seen to belong to a number of these conceptual sequences. In other words, the focus on an application quite radically re-orders the association of chemical knowledge and each bit draws its meaning from the focus of the learning, the application itself.

Consider as an example the lead accumulator, which is one of the applications of chemistry that must be in the short list for having made the greatest change in the culture of many societies, because it has made individuals (both normal and impaired) mobile on land, sea, and in the air. If the chemistry on which this example is based is studied it will include the redox potentials of the electrode systems but only as one piece of chemistry along with topics like the solubility equilibrium of insoluble salts, the reversibility of the physical form of a solid as it goes in and out of solution, and the evolution of gas in systems involving metals and acids. Indeed when the question of alternatives for this application is considered these other aspects to its chemistry turn out to be very critical since there are any numbers of redox pairs that could produce a similar e.m.f.

When this same application is mentioned as part of conceptually oriented courses (as in Figure 4) it is only ever referred to when the redox sequence is being studied and thus many other aspects of its chemistry and social impact are overlooked.

3 Teaching Chemical Education for Better Understanding

It is now appropriate to address the second key question since a growing body of recent research is throwing light on it.

Almost the whole of the efforts of curriculum reform in the last twenty years has assumed that chemistry is learnt as a result of two sorts of classroom interactions. These are shown as (a) and (b) in Figure 7. The first assumes that most learners in school have blank minds as far as chemical knowledge is concerned. These blank minds encounter teachers who have chemical knowledge in their minds (S_T) which will be transferred to some more or less degree if the conditions (classroom climate, textbooks, practical experiences, intrinsic and extrinsic motivation, *etc.*) are right. Alternatively, it has been known that some learners do have primitive ideas (howlers or misconceptions) but as in (b) in Figure 7, it has again been assumed that if the conditions are right these will be easily displaced when they encounter the powerful ideas and chemical knowledge of the teacher.

The recent research to which reference has been made is increasingly providing evidence that for many key topics in science education these assumptions are wrong. Studies in New Zealand (Osborne and Wittrock[17]), Germany (Minssen and Nentwig[18] and Duit[19]), England (Sutton[20]), Sweden (Andersson[21]) and Australia (Fensham, West, and Garrard[22] and Mitchell[23]), point to at least two other interactions (c) and (d) in Figure 7. Much of these data are from the 'successful 20%'. In (c) of Figure 7 significant groups of learners have well formed ideas about chemical phenomena (S_{Ch}) that are not displaced by the teachers efforts. Rather, these learners accommodate the teacher's knowledge for school purposes like examinations while retaining their original ideas because they seem more useful for dealing with the phenomena of the real world. Then there are learners, as in (d) of Figure 7 who reject the teacher's knowledge and simply retain their own, becoming 'failures' or dropping out of chemical studies.

Table 3a lists the terms that are being used to describe the learners' ideas and those they meet through the formal teaching of science in school.

In summary, this research indicates that many learners bring to the classroom from their outside and previous experience intuitive knowledge that has been described by the researchers with a variety of terms. In our own research[24] the term 'Children's science' (S_{Ch}) has been used (see Figure 7) because the ideas seem to involve powerful logic but limited experiences, and because a number of the ideas seem to be like those that were orthodoxy in the sciences at earlier periods in their development. For example, many learners have a view of burning that seems to be like that of the phlogistinists.

[17] R. J. Osborne and M. Wittrock, *Sci. Educ.*, 1983, **67**, 489.
[18] M. Minssen and P. Nentwig, *J. Chem. Educ.*, 1983, **60**, 476.
[19] R. Duit, *J. Sci. Educ.*, 1981, **3**, 291.
[20] C. R. Sutton, *Eur. J. Sci. Educ.*, 1980, **2**, 107.
[21] B. Andersson and L. Renström, 'Oxidation of Steel Wool', EKNA Report No. 7, Göteborgs University, 1982.
[22] P. J. Fensham, L. H. T. West, and J. E. Garrard, *Res. Sci. Educ.*, 1981, **11**, 121.
[23] I. J. Mitchell, unpublished results, Faculty of Education, Monash University, Melbourne, 1983.
[24] J. K. Gilbert, R. J. Osborne, and P. J. Fensham, *Sci. Educ.*, 1982, **66**, 623.

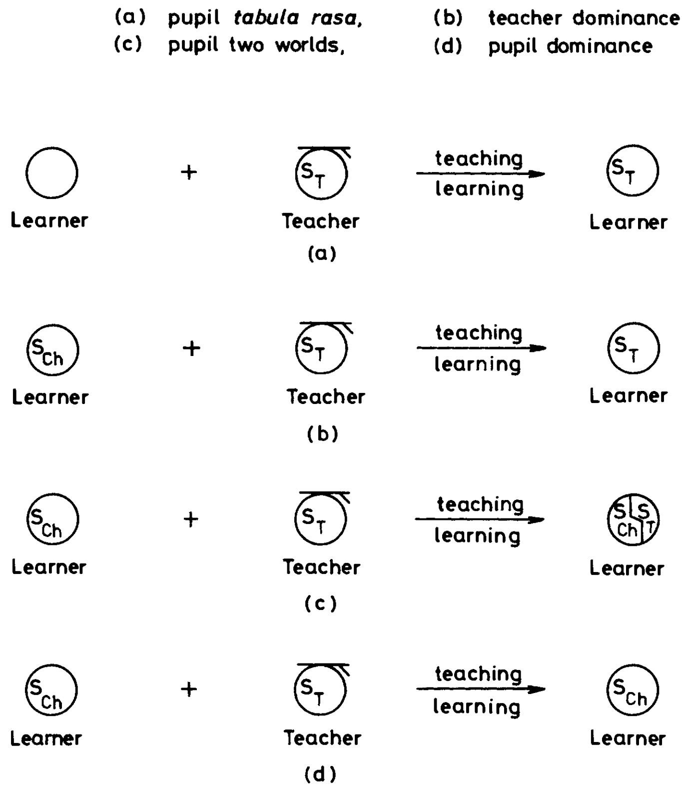

Figure 7 *Interactions between the science frameworks of teachers and their learners*

In school these views, now more commonly regarded as conceptions or alternative frameworks, meet a variety of views of chemistry from teachers. Sometimes these teacher views are like the present public orthodoxy of chemical science or a good textbook. Sometimes they are a teacher's version of this topic or even a view that enables complex topics to be examined—examination science. For example, many learners at school get the impression that the three types of cubic lattices represent a common form of crystal structure, whereas they are in fact rarities among the crystal forms of real solids. They are teachable and examinable.

As Table 3b also indicates, this sort of research also seems to be suggesting (West, Pines, and Sutton[25]) that if the discrepancy between the learners' and the teacher's views is not large (or if the learners do not have relevant views), then evolutionary learning by interactions (a) and (b) of Figure 7 can occur. If, on the other hand, the discrepancies are large, interactions (c) and (d) of Figure 7 are

[25] L. H. T. West, A. L. Pines, and C. R. Sutton, paper submitted to *Rev. Educ. Res.*, 1983.

Table 3 (a) *Some of the terms used to describe learners' ideas and the sorts of science knowledge they encounter in school*
(b) *The consequence of discrepancy between these different conceptions for learning*

(a)

OUTSIDE SCHOOL EXPERIENCES (intuitive)	INSIDE SCHOOL SITUATIONS (non-intuitive)
Naive theories	Scientific theories
Cultural theories	Formal science
Preconscious theories	Teachers' science
Gut knowledge	Disciplinary knowledge
Personal knowledge	Objective knowledge
Children's science	Examination science
Real world theories	
Alternative frameworks	
Children's conceptions	

(b)

DISCREPANCY	LEARNING
Small	Evolutionary
Large	Revolutionary

probable and only by quite radical or revolutionary experiences will the learners' views be much affected.

Some of the chemical topics for which there is evidence that significant groups of learners (15% to more than 50%) hold views at variance with what formal chemistry expects are listed in Table 4.

Several of these strongly held views have made us aware that many learners do not understand the concepts of conservation of matter or of atoms naturally, both of which much teaching of chemistry has taken as almost axiomatic. The ideas about burning and about the destruction of matter as a source of the energy of reactions, and about the non-conservation of atoms now help us to understand why stoicheiometry so often turns out to be a great problem area for learning.

These newly found complexities in the communication of these basic conceptual ideas in chemistry have enabled us to appreciate why the 'understanding' of many of the 20% falls short of our hopes. They also are strong indicators of why at least a number of the 80% never get to grips with chemistry and leave school without benefit from this subject. The alternative approaches discussed in Part 2 for the 80% are much more directly experiential and may have great advantage also to the learning of the 20%.

A Case Example.—A recent study of learners' understanding about the reaction of dilute hydrochloric acid and magnesium ribbon will illustrate some of these findings. This reaction was chosen because it seemed likely to be a simple and familiar one. Each learner was asked to observe the reaction as it occurred in test

Table 4 *Examples of phenomena in Chemistry and learners' views of them (Revolutionary learning)*

PHENOMENON	*EXPLANATION*
Burning	Substances lose mass ('Phlogistonist')
Disappearance in reaction	Matter eliminated as energy ('Einsteinian')
Involvement of gases	Gases are normally air (Air = Oxygen = Gas)
Sub-division of compounds	Essential nature of substances (a non-atomic view)
Existence of phases	Substances have a natural phase. Heat can melt or heat can boil but no sense of three phases as reversible and simply a function of the conditions
Nature of matter	Fusion of experiential reactions with objective properties

tubes held by them until the strip of ribbon had finished reacting with the excess acid. They were then individually interviewed concerning their observations and explanations for the reaction. Table 5 lists some common responses from the samples of learners who were drawn from the classrooms at different levels in several schools. The youngest group of learners had not encountered chemical symbolism or the use of equations to describe reactions, while the older learners were familiar with both.

The first striking result was that the older groups reported so much less of the easily observable. There seems to be a tendency for more chemical learning to lead to less observation and to more mere repetition of the words used by teachers to describe this reaction. This may be symptomatic of a tendency for conceptual chemical education to divorce itself from the realities of chemical systems.

A second finding was the varied and uncertain answers given by the youngest group to 'what happened to the metal?' and the confident convergent answer from the older students. However, this difference was more apparent than real when the older ones were asked 'What do you mean by 'dissolves'?' This question elicited varying ideas. Some learners thought the magnesium would now be ions clustered at the bottom of the tube because 'they are heavier than water'. Others thought they dissolved enroute to turning into the energy of reaction.

One other result was the distinctly different answers to the question 'Where does the gas come from?' The answer, 'the acid', was re-inforced by the teachers in most cases and seems to be an example of teacher or examination science. Observationally, 'the metal' or 'the metal–acid interface' are clearly more correct and in fact the product hydrogen has two components, one of which comes from the acid and one from the metal.

Questions like 'Where does the energy come from?' or 'What has happened to the acid?' produce answers which indicate a complexity in this system that was

Table 5 *Some responses to the reaction of magnesium metal with acid*

RESULTS OF INTERVIEWS

	Year 9 14+	Year 11 16+	Year 12 17+
What do you observe?			
	droplets up tube		
	tube gets warm	...(sometimes)	...(sometimes)
	metal disappears	Mg dissolves	Mg dissolves
	bubbles of gas	H_2 bubbles	H_2 evolved
What happens to the metal?			
	dissolves	dissolves	dissolves
	not sure		
	disappears		
Where does gas come from?			
	metal	acid	acid

unexpected to the researcher. Among the total findings there are data from particular schools that suggest evolutionary learning and other data are indicative of the evolutionary gap.

Ausubel[26], twenty years ago, when the great phase of curriculum development was getting underway, urged that the way to improve the understanding of learning was to *'find out what the learner already knows and teach him accordingly'.*

So far the research that has been described has been much more concerned with the first clause of Ausubel's dictum than with the second. There has been some research on what it may mean to 'teach accordingly', but insufficient as yet to report in this general review.

This type of research has, as indicated above, shown that the apparently simple task of asking learners questions (which many teachers may have thought they were doing) is one that can involve quite different types of teacher–learner interactions. In research, these interactions are entertaining and fruitful—full of ha-has and ah-ahs! Their transfer to the general repertoire of teachers in classrooms could be just as rewarding, but given the strength of present teaching patterns it is not likely to be easy. It is, however, a worthy challenge if the two questions of this paper are to find answers in the rest of this century.

[26] D. P. Ausubel, 'Educational Psychology—a cognitive view', Holt, Rinehart, and Winston, New York, 1968.