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**THE PRACTICE OF CHEMISTRY EDUCATION
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Chemical education in Europe: Curricula and policies

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THE PRESENTATION OF CHEMISTRY LOGICALLY DRIVEN OR APPLICATIONS-LED?

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ABSTRACT: The chemistry curriculum in both school and higher education tends to be based on the logic of the subject, with applications of chemistry added as footnotes. This paper seeks to look more closely at the nature of the content to be taught and suggests that it is useful to consider an applications-led approach rather than an approach which is based on the traditional logic of the discipline. By an applications-led approach, it is meant that the chemistry to be taught is *determined* by applications from life and NOT by the logic of the discipline of chemistry. The paper will look at both school and university chemistry and give examples of materials that have been used successfully. This paper is based on a plenary workshop offered at the 5th ECRICE, 1999. [*Chem. Educ. Res. Pract. Eur.*: 2000, *1*, 381-392]

KEY WORDS: *Secondary school curriculum; higher education curriculum; applications; curriculum design; chemistry teaching materials.*

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INTRODUCTION

In the 1960s, new chemistry syllabuses emerged in many countries at school level and higher education chemistry courses were adapted to follow these. The impact of these changes has been extensively reviewed elsewhere - see, for example, Hodson (1985). In Scotland, a new syllabus at school level was introduced in the early 1960s (Scottish Education Department, 1962) and revised later that decade (SCEEB, 1969).

A common feature of such syllabuses at both school and higher education levels was their attempt to be up to date and to present the content in a logical order. There are two fundamental issues to consider: on what basis is the content of the syllabus to be selected and what principles can be used to determine the order of presentation? It has been argued elsewhere (Johnstone, 2000) that a better approach might be to present the material in an order that takes into account the psychology of the learner rather than the logic of the discipline.

Over the years, numerous studies have considered ways by which the content of a syllabus can be determined. In a sad comment, de Vos, van Berkel, & Verdonk (1994), in looking at school and general chemistry courses together, note that the concepts to be taught have not altered, even over a long period of time. They observe that applications usually appear in syllabuses as ‘footno

Using numerous examples, Hawkes (1992), in a hard-hitting comment, seeks to demonstrate that much that is taught in chemistry courses is irrelevant, lacks real meaning for students and is often only partially correct. He asserts that we do not really know what are the fundamentals, noting that, “We have chosen to teach fundamentals that are of little value to the student while neglecting fundamentals of greater value.” He suggests that there is a need to analyse what chemistry is actually required by various groups in society including the educated reader and the decision-taking citizen.

In his reflective essay, Fensham (1985) observes that school curricula are determined by the scientific concepts that are foundational for the development of the science disciplines. He notes that, as a result, this “can take so much time that the excitement of contemporary science and its possibilities for social usefulness can be, and are, often overlooked and omitted.”

Focussing particularly on early levels of higher education, Gebal (1999) notes the importance of using materials familiar to students and that this has beneficial effects for students majoring in chemistry as well as those for whom chemistry is a support subject. She notes that, “The chemistry needed to become a good citizen or to lead a fruitful life must be determined.”

This paper will look at both school and university chemistry and give examples of materials that have been used successfully in approaches that are more application-led in nature.

APPLICATIONS-LED

Chemistry embraces many abstract ideas and the learner may well perceive chemistry as an abstract discipline with limited connection to day-to-day living. The learner may fail to see the contribution of chemistry to the development of society. The logical perspective tends to start at the atomic level, looking at energy and structures as molecules are derived. Applications are sometimes added towards the end. However, it is equally possible to reverse this, starting with applications and developing the chemical understandings required to make sense of these (Figure 1).

There are several examples of this approach at very different levels where applications can introduce topics or illustrate the way chemistry develops (Percival, 1978; Reid, 1981a; Reid 1999a). Recently, Bailey (1997) has described a module, based on chemistry, which aims to

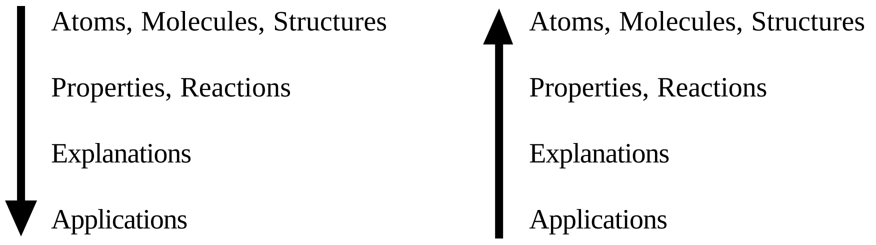

FIGURE 1. *A change of direction.*

develop communication skills. It is even possible to build an entire course around applications and an early quite adventurous example is that of Sellinger (1986).

Thinking of the type of approach typically adopted in school chemistry syllabuses, Fensham (1985) notes that , "...the majority of the school population learns that it is unable to learn science as it has been defined for schools." He argues strongly that basing school curricula on the logic of science or on the science that is meaningful to scientists will produce a syllabus that will fail. He advocates "a view of science *from the position of society* rather than one from within the science itself."(italics mine). This is a most insightful perspective. He refers to two criteria for selection of content: the content (science knowledge and its associated skills) should have social meaning and usefulness (potential of directly enabling the learners to enhance and improve their life beyond school) for the majority of learners and should assist learners to share in the wonder and excitement that has made the development of science such a great human and cultural achievement.

Williams (1993) takes a similar line from a much broader perspective when he argues that one of the functions of science education is to set understanding in its cultural role, leading to a deep appreciation of the nature of man in his surroundings, physical and biological. He sees this as potentially humanising.

Starting from an established chemistry syllabus, Reid (1980) specified five areas where attitudes might arise from studying chemistry: the historical dimension of chemistry, the social impact of chemistry on our life style today, the industrial implications of chemistry in our society, the economic implications of chemical activity in our society, the socio-moral implications of chemistry. Is it now possible to *define* a chemistry curriculum starting from such a list ?

This could be considered at several levels. It is possible to think in terms of a single teaching session that is applications-led. Indeed, skimming through many science education journals provides numerous stimulating examples of this kind of approach. The approach being advocated here can be described as follows: a problem is presented. This problem involves an application of chemistry to be studied. In discussing the problem, the necessary chemistry is unfolded and makes sense in the context of the application. This approach is developed more fully elsewhere (Reid, 1999b).

WHY STUDY CHEMISTRY?

On average it seems that, for every 100 pupils coming into a school, perhaps only 1% goes on to a degree in chemistry, with, perhaps, another 2% taking a degree heavily dependent on chemistry. On this basis, there is no support for the notion that secondary school pupils should take chemistry in order to prepare them to be chemists. However the latter argument is remarkably persistent. It is often assumed that the chemistry to be taught at each level is determined by the requirements of the level above. This is a wrong approach in that the population at the next level up is only a tiny fraction of the level under consideration, meaning that the choice of chemistry to be taught is determined by the needs of the minority (see Figure 2).

A better way is for each level to use what chemistry is there from the previous level but it should NOT determine what is to be taught previously. In an interesting design of a General Level University course, it has been shown that success in the course need not be determined by

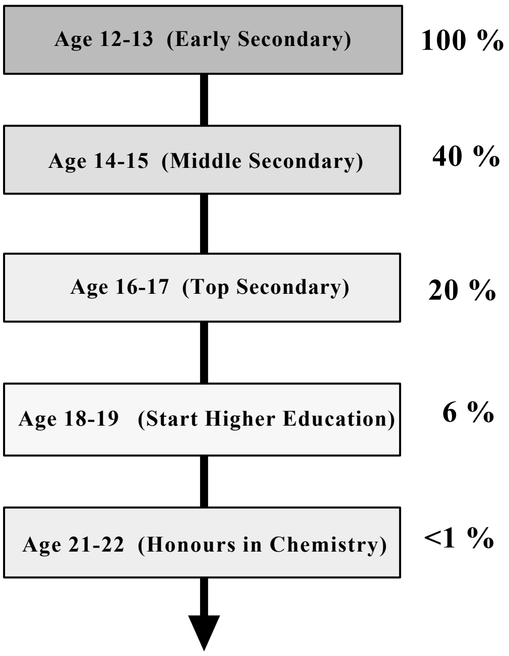

FIGURE 2. *Chemistry uptakes in Scotland.*

the chemistry knowledge gained previously (Sirhan, Gray, Johnstone, & Reid, 1999). Thus, there is minimal support for the teaching of school chemistry to prepare pupils for chemistry-based university degrees. Indeed, even with those taking university degrees in chemistry and allied subjects, a high proportion do not enter careers where they will practice the chemistry they have learned. Kesner, Hofstein and Ben-Zvi (1997) assert that, "In recent years, science educators and curriculum developers have realised that science is taught not only in order to prepare for university studies and careers in science, but also to become citizens in a society that is highly dependent upon scientific and technological advances." They argue for the relevance of science to daily life and they refer to the importance of the implications of chemistry being stressed.

Textbooks, of course, both reflect and influence curricula. In the current economic climate in publishing, textbooks tend to reach the market only if they reflect the general trend of syllabus construction. This has an inhibiting effect on change: new ideas are inhibited for lack of textbook support while radical changes in textbooks are curtailed by lack of change in what is actually being taught. Looking at chemistry textbooks aimed at higher education, Gillespie (1997) has noted the lack of change over many years and has commented that "they have not succeeded in interesting the vast majority of students or in providing them with an understanding of chemistry."

Chemistry, perhaps, has a major role to play in introducing the "way of knowing" that is science. Influential philosophical contributions have been made by Phenix (1964), and Hirst and Peters (1970). Whitfield (1971) picked up these themes and explored them in some detail in the secondary school situation and his approach has had a prolonged influence on school curriculum

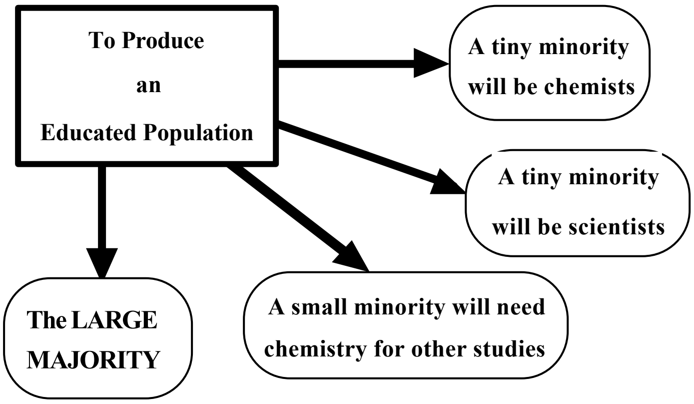

FIGURE 3. *Why study chemistry at school?*

construction in Scotland. Following these types of approach, the unique contribution of the sciences in the curriculum may be to develop the skills so that the learner can address questions of the physical world in such a way that meaningful answers can be obtained.

Thus, the chemistry curriculum can be constructed by exploring three themes:

(1) What are the questions that chemistry asks ?
(2) How does chemistry obtain its answers ?
(3) How does this chemistry relate to life ?

On this basis, there is a very strong argument that all (not some) of our school pupils should be led into an appreciation of the way chemistry seeks to obtain answers and then on to some of the answers that underpin our modern society and the way it works. There is an even greater argument that this process is developed further in higher education.

Of course, like every other subject in the curriculum, chemistry curricula must take into account the likely destinations of school leavers and graduates and the kinds of skills that potential employers might seek. (See Harvey & Green, 1994; Harvey, Moon, & Geall, 1997, for a UK analysis.) Their work has outlined many intellectual and thinking skills (eg problem solving, critical thinking) as well as attitudes (e.g. informed judgements, social awareness) and social skills highly prized in the workplace (eg teamwork skills, communication skills). At higher education level, Percival (1976) looked at development of several of these skills (including team work, communication, problem solving) while others have focussed particularly on critical thinking skills (Byrne & Johnstone, 1987a, 1987b; Overton, 1997; Garratt, Overton, & Threfall, 1999).

At school level, numerous sets of teaching units exist, many of them presenting the pupils with a problem to be solved, the problem being derived from the application of chemistry in society (Reid, 1981b; Johnstone, Morrison T. & Reid., 1981). In many of these early developments, applications of chemistry were starting points and the relevance of the skills that were being developed was seen to be high in that the problems were set in real-life contexts.

USING APPLICATIONS

In an application-led approach, a problem depending on the application of chemistry can be the starting point. Students are allowed to work with the relevant chemistry to understand and move towards a solution. Such problems can include diverse themes like the choice of fibres for particular market applications, the formula of ozone, the development of anaesthetic compounds useful in surgery, chemical solutions to legislative demands about pollutants, the polywater controversy, energy content of various fuels and so on.

Two aspects have to be stressed. Firstly, it is important to recognise that the problem applications used must relate to the learners. Sometimes, applications that are seen as highly relevant to the trained chemist are not perceived that way by the learners. In this, industry may not always be a good starting point in that it is not part of the ordinary normal experience of the learner and may be perceived as just as abstract as any more traditional approach to chemistry.

Secondly, the proposal here suggests that, in such an applications-led approach, the ‘real-life’ problem can define the area of chemistry to be explored and may provide the framework for the more traditional teaching that follows. Some examples of teaching units that build on these principles are now described .

SOME EXAMPLES

In ‘From molecule to marketplace’ (Reid, 1999a), the students work in small groups looking at a table of data about the properties of eight un-named fibres. Given four marketplace applications (making boats sails, underwear, a man's shirt, a lady's pair of tights), they are asked to select the fibres that would be most likely to be appropriate. Having come together as larger group, they discuss their choices. At this stage, the unit can be seen as *defining the chemical agenda*. The teacher can move on to look at the kinds of structures that account for the range of properties or focus on a single structural feature like hydrogen bonding. The unit can initiate a major study of the polymer groupings, based on the kinds of linkages between monomer molecules or the focus could move to polymer synthesis.

In ‘Choosing an anaesthetic’ (Reid, 1999a), students, working again in small groups, re-live a small part of the kind of activity that went on in the search for modern anaesthetics. They study data for various compounds in seeking to take a decision about which compounds are worth selecting for further testing. Coming together, they discuss what actually happened in recent history. At this stage, the unit again can *define the chemical agenda* for further study. It may lead into discussions of ethers and halo-compounds or the way these two structural features both appear in the most recent anaesthetics. They can study flammability or solubilities or look at structural features.

At school level, it is possible to teach the chemistry of sulphuric acid in a traditional way, making appropriate references to industrial applications. In an alternative approach (Reid, 1999a), the pupils work in groups to plan the construction of a manufacturing unit to make the acid, taking into account raw materials, required product quality, available technology, scale of operation, and transport and communications. The need to build a production unit arises from the demands of the marketplace. However, different groups are doing this at different points in history, given the data for the time, and they come to different conclusions. Not only have they uncovered a considerable amount of sulphuric acid chemistry but they have also begun to appreciate the impact that chemical industry has on society and the fact that, while chemistry does not change, industry does change, with considerable social impact. The same approach can be used with university students, leading to a development of the thermodynamics and kinetics of the process along with an understanding of the way the chemistry is used to design a production unit that fulfils ever increasing pollution requirements. Again, the application of chemistry *defines the chemical agenda* for further study.

Many years ago, Percival (1978) designed a teaching unit to illustrate the way science moves as ideas develop, are tested and are then rejected. This involves groups of students following the polywater controversy by reading and summarising key papers from the library in three phases. In the first phase, the early papers show the idea developing and the theory emerging. The second phase shows the beginnings of doubts and questions. The third starts to build the evidence that eventually demolished the theory. The application *defines the agenda for study,* in this case for a library search.

CONTEXTS AND APPLICATIONS

There have been numerous attempts to present chemistry in a context. Sometimes this is social, sometimes industry is employed. Thus, for example, the Salters "A" Level Chemistry course in England (Salters, 1994) has used this approach. This approach is useful in that it has attempted to set the chemistry in a context. However, although the context has influenced the content, much of the content is still largely determined by the demands of higher education.

In a study conducted by Ramsden (1997) in which she looks at the Salters' course at General Certificate of Secondary Education (GSCE) in England and Wales, she compares the SaltersÕ course, which she describes as context-based, with the traditional linear GCSE courses. She notes that both courses are equally effective (or, at times, ineffective) in developing key understandings but, significantly, there appears to be greater enjoyment among pupils following the context-based course and that the pupils are more interested in what they are studying.

Sellinger's course (1986) looks at chemistry in relation to the laundry, the kitchen, the boudoir, the garden, the medicine cabinet, the dining room, as well as the chemistry relating to paints, plastics, metals, glass, fibres, energy users, and consumer choice, again the applications in life *defining the chemical agenda* for further study.

An attempt is made here to distinguish between context led approaches and applications-led approaches. In the former, students are introduced to chemistry by showing them more of the chemistry as it is actually 'done' in today's world, by researchers and industrialists, applying basic ideas in appropriate contexts. In an applications-led approach, students are introduced to the chemistry that is needed to make sense of the world around as they know it, giving insights in to the perspectives and methods of chemical enquiry as well as its outcomes. *The key point is that the actual chemistry to be taught is determined by the applications used.*

SOME OUTCOMES

There is a considerable accumulation of evidence, much from many years ago (Reid, 1980; Johnstone, & Reid, 1981; Byrne & Johnstone, 1983), about the kinds of outcomes that arise from the use of such materials. Overall, the evidence is quite clear in suggesting that this type of approach is popular with students and there are clear gains in the development of skills and attitudes.

Another fascinating piece of evidence came to light recently. In the Scottish Secondary school system, Standard Grade Physics (Scottish Qualifications Authority, 1997a) is a national examination sat around age 15-16. In Scotland, Physics is popular and has a good status without being regarded as impossibly difficult. The syllabus is built around a number of application areas (like transport, space, communications, health) and, in a very limited way, the physics as a whole is applications-led. By contrast, the Standard Chemistry syllabus (Scottish Qualifications Authority, 1997b) is more traditional, carries a similar status but is not applications-led in any way.

These two syllabuses were introduced in the early 1980s and it is an interesting observation to note that, immediately after the introduction of the Physics syllabus, the proportion of school pupils electing to continue their studies in Physics (at the Higher Grade, the next examination) increased. On average, about 55% of pupils studying Physics at Standard Grade choose to stay on to study for the Higher Grade, making the Higher Grade Physics course the fourth most popular subject (after English, Mathematics and Biology). The figure of 55% is extraordinarily high. The equivalent figure for Chemistry is about 45%, with Chemistry being the fifth most popular subject at the Higher Grade (Scottish Qualifications Authority, 1990-1998).

Could it be that the applications orientated course at Standard Grade is attracting school pupils to stay on in Physics and attempt the Higher Grade? Although there may well be many other factors, ongoing unpublished work where pupils views have been sought seems to confirm that the applications-led approach - even although it is only a partial applications-led approach - is a factor (Reid and Skryabina, 1999). This is consistent with the observation that applications-led teaching materials are apparently always associated with very high levels of enjoyment when pupils and students are surveyed. Enjoyment is linked to a sense of satisfaction, to higher levels of motivation and, then, to greater commitment. Have we, in our attempt to present chemistry as a logical discipline not only lost its relationship to the psychology of the learner but also lost the vital ingredient that allows the learner to perceive their studies as meaningful in relation to their lifestyle, their attitudes and their aspirations ?

AN APPLICATIONS-LED APPROACH: LOOKING FORWARD

To illustrate the approach, we can consider the design of an applications-led approach at secondary school level. It is important that the application areas relate to key areas of teenage lifestyle, - themes like: music, cars and transport, cosmetics and beauty, health and consumer choice, food and drink, clothes, colour and decoration, pollution and resources, our society and other societies. It is likely that five broad areas will be important - see Figure 4.

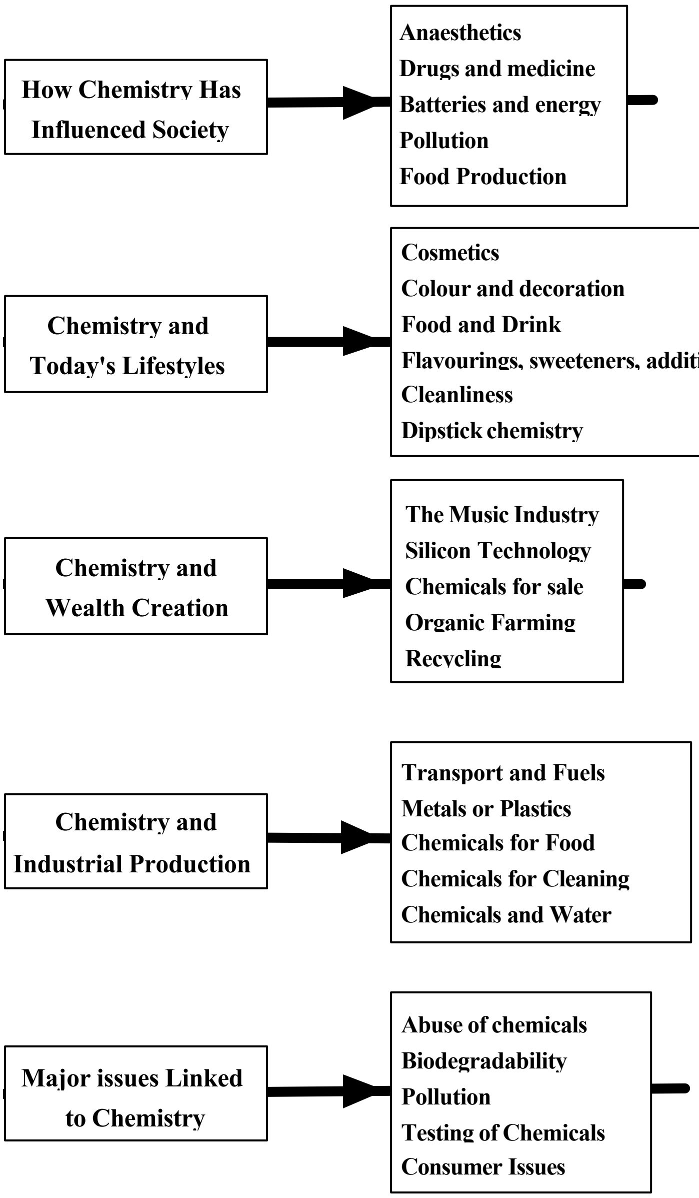

FIGURE 4. *Applications areas.*

Possible starting points will include: clothes, washing and dyeing; food and drink; cooking; cleaning; cosmetics and cleanliness; drugs and medicine; colour, decoration; consumer choice, analysis; resources. The above list is merely suggestive and not comprehensive in any way. Different societies, cultures and social contexts will suggest changes, additions and deletions.

These are only examples but what is being advocated is a paradigm shift in our thinking as we seek to design syllabuses and to plan the individual learning experiences for students in chemistry. The same principles will apply at all levels but the choice of applications and the depth will vary widely.

The paper has sought to draw together diverse evidence that suggests an alternative way by which chemistry curricula might be constructed. In this way, applications drawn from life that are meaningful for the learners provide the framework. The chemistry to make sense of these is introduced as required so that the learners can make coherent sense of their world. While it is extremely difficult to gather evidence which would conclusively demonstrate that this approach is the way forward, it is hoped that what has been observed strongly supports this way of thinking.

FINAL COMMENT

A number of years ago, in one school with a mixed social intake, a syllabus that reflected some of the ideas in this paper was introduced. Some five teachers were involved. The course was the first real chemistry that the pupils had met and their age was about 13. The idea of the elements was presented as ‘building blocks’, analogous to the letters in a alphabet that could form an apparently endless array of words. The periodic table was seen simply as a device to display these elements. Over the year, the pupils started to look at their world (the air, water, the sea, rocks and minerals, the atmosphere) with a simple agenda: what elements could be found and what was mankind doing with what was there? Many fundamental chemical ideas just arose naturally, eg. the concept of bonding, reactivity, physical properties of matter, energy and bonds, states of matter. The course was descriptive, based on the world around, applications orientated, and it avoided quantitative aspects. The effect on the pupils was remarkable. At the end of the year, *every* pupil who was of sufficient ability, *without exception*, opted to take the chemistry course for the ensuing two years. This nearly doubled the chemistry uptake in that school, a most encouraging outcome!

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