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Chapter 12 Chemistry in the Secondary Curriculum

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This guidebook is not intended as a prescriptive document which tells teachers what should be taught in secondary chemistry, but rather has looked at key issues in teaching some of the core (and often problematic topics) which have commonly been included in secondary school courses. Just as the book is not designed to be prescriptive, we have also avoided the temptation to follow some particular curriculum formulation or examination specification and so to seek to 'cover' the content of any specific government document or examination authority. We hope that the guidance in this book will continue to be useful despite future specific changes in curriculum or examination courses. There are continuing important debates about what science should be taught during the secondary schools years, and what chemistry deserves its place - especially where chemistry is a compulsory subject for all students.

Chemistry for enthusiasts

Such debates inevitably draw upon different ideas about the purposes of formal education, and so the justification for setting out the particular things that we expect all young people to meet during their schooling. Quite rightly, the idea that the school curriculum must include all the chemistry likely to be useful for the minority going on to study post-secondary chemistry, and that this should be taught to all students (perhaps with an implication that most will fail to engage with, or make sense of, much of the material, aiding the selection of those most suitable for progression), is no longer seen as viable or appropriate.

Yet, despite this, it is clear that part of the purpose of a curriculum is to offer learners a flavour of different subjects - both to help them decide whether a particular subject is of sufficient interest to consider studying it further, and to provide a basic understanding of the core ideas suitable for progression. That suggests that (i) all students should meet enough (representative) chemistry to support judgements about whether this is a subject they are interested in selecting for further study in some form after completing secondary education, but (ii) there should be curriculum differentiation that allows different groups of students to study more or less of the subject. This can meet the needs of those who are keen to take further courses, as well as those who have had their taster, and decided this is not a subject they wish to spend too much time working on.

When I first entered teaching, in the English educational context, many students dropped chemistry at age 14, having decided (or sometimes been advised) they had studied enough of the subject. That often seemed premature given the limited notions of future careers that many students have at that age. In the early 1990s, there was major change, and a National Curriculum was introduced that required all students to study broad and balanced science to age 16: that is, science that included some chemistry topics alongside topics from biology and physics and some earth science and astronomy (although the subject names, such as 'chemistry', were inadvisably excluded from all the official curriculum documentation, despite the labels being useful to introduce students to the nature of the main science disciplines).

That one-size-fits-all model did not meet the needs of many students, and in recent years we have seen a more sensible approach adopted in England, so that all students meet some chemical topics throughout the secondary years, but with more variety in the types of courses that can be offered to suit the needs for different student groups. It took quite a few years before the government recognised the rather obvious fact that it was not labelling the contributions of the separate disciplines that made a science curriculum unsuitable for the full range of secondary students, but rather the prescription of a great many common topics that teachers had to present, whilst trying to engage students of all abilities, aspirations and interests. In recent years, a more reasonable approach of identifying a common core, which can be supplemented by alternative optional elements, has been adopted - leaving school departments and teachers to find the right curriculum for groups of students identified in the local teaching and learning context. Making these important decisions should be informed by consideration of the different purposes of education.

Chemistry for citizens

In the twenty first century, we recognise the rights of children to be involved in the major decisions that effect their lives. It has also been found that providing young people with some elements of choice in what they study, or allowing them to select particular activities to meet specified learning goals, can be highly motivating for many students. This always needs to be balanced against their status as minors, that is, as young people recognised as not yet in a position to make fully informed and considered decisions about what is in their best interests. Many secondary age students would, given a free choice, rather not study much of the curriculum that (adult) society might prescribe, and therefore there is a difficult balance to be reached in judging how much input students themselves should have in decisions about what they will study. Teachers are often given the power to make some of these decisions for the young people in their care, and this brings responsibilities to make those decisions carefully and after due consideration.

It is widely accepted that a key role of school is to prepare young people for their place in adult society: where they will make decisions about consumer habits; acting (or not) on health and medical advice; engaging in civic life (perhaps by supporting particular organisation and pressure groups); and voting for their political representatives in consideration of mooted policies about such matters as environmental protection. Science, including chemistry, clearly has a major role here, as a great many of the decisions adults will face rely on understanding and critiquing arguments based upon (or claiming to be based upon) scientific evidence. It is essential therefore that young people understand something of the nature of scientific processes; and of the nature of scientific models and theories, and how they relate to evidence. Of all the science subjects, chemistry offers exceptional opportunities to appreciate the relationship between evidence based on observation of the natural world, model-building as a means of making sense of evidence; and theoretical knowledge as a means to build up general explanations and make fertile predictions where solid evidence is not yet available. Chemistry, after all, is largely based upon an extensive set of theoretical models relating to entities (molecules, ions, electrons) which cannot be directly observed, but which support a coherent and extensive understanding of the material world. That is, a coherent and extensive understanding which allows us to create new substances and materials that quite possibly have never previously existed in the universe, designed to meet particular needs (and increasingly to do so in ways that are sustainable).

In particular, all citizens should appreciate both the strength of science as a means of producing robust and reliable public knowledge, and the inherent limitations of science. All scientific knowledge should be considered provisional in the sense that the scientific attitude is to always be prepared to take another look when there is reason to do so. Often the case seems to have been made: but science always admits appeals based on convincing new evidence. This is an essential issue for teachers when, understandably, most of the chemistry met in school is well established and seems beyond questions, yet much of the chemistry and other science which is part of public discourse seems to be the subject of uncertainty and disagreement. This can be understood when students appreciate something of the processes by which ideas – initially someone's unsubstantiated imaginings – are tested and developed, and slowly come to be seen as worthy of being considered sound (yet never quite certain) scientific knowledge. Clearly a very important part of school science must be focused on teaching something of the essential nature of science and its processes. This is the theme of the companion handbook on *Teaching Secondary How Science Works*, but the authors of the present volume have offered suggestions for where these themes can be emphasised in chemistry topics.

However, whilst encouraging a focus on teaching about the processes of science, it is important not to lose sight of the products of those processes: the models and theories themselves. Teaching about key concept areas in chemistry (particle theory; the periodic table; types of reaction; etc) is important in its own right. For if citizens are to understand public debates relating to chemistry (ozone depletion; safe storage of nuclear waste; pollution from combustion of fossil fuels etc) then they will need a minimal level of literacy in terms of the core conceptual ideas of chemistry: what a molecule is; what happens in a chemical reaction; how chemical changes may be influenced by changing conditions; etc.

It is clearly not possible to set out with confidence a canon of agreed ideas that comprise what future citizens will need to know to engage with public discourse about socio-scientific issues: but there is a good case for thinking that many of the key topic areas covered in the present book are at least respectable candidates. The more chemistry we can teach, and the more sophisticated understanding we can offer, the more likely we are to prepare future citizens for this aspect of their future lives. Yet, of course, this always has to be balanced against all the other competing areas of knowledge that will have claims on a place in curriculum.

Chemistry for culture

Certainly chemistry teaching should be part of a balanced education. One perspective, the notion of a liberal education, would suggests that all young people should be offered the tools to appreciate the wider aspects of their culture of their society. Culture is somewhat contended: at one time it might have seemed that opera, sonnets, and classical literature should be major components. Arguably, understanding culture today might be better supported by an education about soap operas, rap and graphic novels! It certainly seems that during compulsory schooling, young people should be introduced to something of such areas of music, theatre, literature, and fine arts, even if the questions of which examples should be included is less clear.

The scientist and novelist, C P Snow famously referred to the 'two cultures' and bemoaned that whilst a person knowing little of art and literature might be considered somewhat uncultured, ignorance of such scientific topics as thermodynamics seemed to be much better tolerated (sometimes almost celebrated) in polite society. In the Twenty First century such an attitude should not be acceptable. Modern life is highly dependent on science and the technologies it underpins. Moreover, human actions in the world have led to widespread extinctions, immense loss of habitat and resources, and potentially threaten the global environment as a suitable home for many living species – certainly including homo sapiens on the scale of current and projected world populations.

Science has not caused these problems - they are the result of human (individual and collective) decision-making and actions – but science has provided the tools for much of the damage. Science also offers the means by which we can hopefully find ways to better live in balance with our environment, and so facilitate the survival of the ecosystem in something like its current form. Science tells us that the earth and its biota has faced a number of previous major changes, and so there is good reason to suspect that even if we cannot protect the environment from the implications of human activity, it will lurch into a new stable state, and life will probably carry on. However, that new stable state will not be the earth we know, and many major groups of animals and plants will probably not survive the dramatic change as a new equilibrium begins to take shape, providing an ecology that will allow new species to evolve and dominate. Quite likely, no humans will be around to see what the new world will be like.

Some would argue this is pessimistic, and the effect of human activity is exaggerated: but there is a broad scientific perspective that we have put excessive strain on the natural ecosystem, to such an extent that we may well be forcing the system past some turning point - beyond which it is likely to shift to a new state less suitable for human habitation. If this view is correct (and it seems a brave or foolhardy gamble to guess otherwise) then only people, working together across national boundaries, can avoid such a scenario. Assuming the human will and commitment is there, it will depend upon science to provide the essential know-how and technologies.

In this context, science cannot be seen as an optional add-on for being cultured: rather science must play a key part in a liberal education to create societies that are empowered to bring about positive change. A key part, but certainly not the only component: because the people who will be charged with this work will also require a knowledge of ethics, of politics and diplomacy, of human nature, of rhetoric, of economics, of history and international relations. These future leaders will rely upon the understanding and support of society in general. To assure humankind's future, we need science to be seen as a part of our common culture: a part that is closely interlinked with other important areas of human knowledge and experience. This could be seen as a strong argument for secondary science courses that include careful study of socio-scientific issues.

Chemistry for workers

Chemistry can therefore contribute to the knowledge needed by individual citizens, and as part of the general education that can inform the cultural context for societies to work together for the good of people worldwide. But chemical knowledge will have stiff competition for the available space in a core curriculum suitable for all secondary learners.

There will be more scope for the elective chemistry that some students may take on top of such a core ‘entitlement’ curriculum. School is, in part, preparation for the world of work, and some may argue for vocational chemistry to support those looking to follow particular career paths: chemistry for nursing, or for working with animals, or for hairdressers and beauticians, or for technician work. Here there is an important argument about the distinction between education as part of schooling and training for particular work. Schooling should provide the basic conceptual framework upon which more specific vocational training can be built. School chemistry may well have a role in vocational preparation in that sense, but arguably schools should not be taking up the roles of training up workers for specific jobs. It seems likely that the basic chemistry needed as a background for vocational courses is likely to be in line with that needed by citizens and cultured members of society: understanding of basic concepts that support further more specific learning in whatever topic and context individuals may later meet in their professional or civic lives.

It could be argued that much the same is true of the future chemist. After all, if schooling provides the basic conceptual background for the learner who might later need to learn more specific chemistry for a particular job, then why should it matter if that job will be as a hairdresser, a school laboratory technician, an industrial process chemist or an academic research chemist? Traditionally universities have expected undergraduate students to arrive with strong background knowledge from college level courses, that - in turn - required a broad prior knowledge of chemistry from secondary school study. However, if schools provide a sufficient background in basic principles to allow the identification of those who are fascinated by chemistry and have aptitude for the subject, then it should not be beyond college and university courses to fill-in any required specifics. This may require adjustment of post-compulsory curricula: but as long as secondary education includes a sound background in the fundamental concepts of the subject, such an adjustment should be relatively easily accommodated in further and higher education.

So, arguably, a great deal of the detailed material that might be included in secondary courses is not essential for citizenship, for a liberal education, nor for progression to higher study of the subject: this material does not have to be widely learnt to safeguard democracy, culture or even the chemical sciences. This is surely true. For example, it is hard to argue that a detailed study of trends and properties in several groups of the periodic table (as many students may have studied some decades ago), whilst it may provide a useful context for learning and reinforcing key concepts, should actually be considered in any sense essential to a sound education. Providing the basic chemical concepts are well understood by the end of secondary school, such detailed surveys of particular chemistry can always be undertaken later by those with a good reason to study such material. The same applies to the different homologous series of organic compounds: their chemistry is interesting to some students, and certainly of value for some purposes, but has limited claim on being a core part of school learning.

From such a perspective there are good grounds to see much traditional upper secondary school chemistry as a luxury that has limited claim on curriculum time. This has been shown by the success of courses that teach chemistry through the everyday contexts of major areas of application (transport, food production, fabrics, etc), and those that focus on socio-scientific issues (global warming, pollution, sustainable development). These courses can draw upon the specific chemistry that is most relevant, given that school science can only ever consider a small proportion of the ever-increasing chemical knowledge base. That said, there is a strong argument for suggesting that time is spent teaching chemical basics prior to setting out on such courses. So one approach would see chemistry in lower secondary science (e.g. for 11-14 year olds) setting out the basic conceptual foundations of the subject, and providing a basis for supporting (and being reinforced through) later contextually based courses, or courses focusing on social issues that are likely to interest and engage many upper secondary students (e.g. 14-16 year olds).

Chemistry for the gifted learner

For many students of this age, chemistry motivated by problems and issues of obvious importance and relevance is more likely to maintain their attention than a more theoretical ('traditional') type of course which is organised around the internal logic of the subject itself. However, we should be aware that different groups of students have different needs. There certainly are some students of secondary age who will be fascinated by the disciplinary structure of chemistry and will be strongly engaged by exploring the development, coherence, and limits of its theoretical apparatus.

Such students are likely to be those labelled with terms such as ‘gifted’ (although this is a term that is not well defined, and risks creating an artificial distinction when a wide range of secondary students can show exceptional abilities in some aspects of chemistry). These are the students who thrive on a more intellectually demanding fare, and for whom the abstract and theoretical nature of chemistry as a science is not a turn-off, but a welcome opportunity to challenge their thinking. For example, these are the students that in the context of the English curriculum for many years (under the national curriculum of the 1990s and early years of the 2000s) found secondary science to be an unsatisfactory survey of a great many topics, each studied superficially, and learnt in terms of rote phrases appreciated by examiners - rather than in terms of opportunity for extended engagement with underlying conceptual patterns. These students did not find secondary science too difficult – just too shallow, and lacking true intellectual engagement.

Chemistry, when taught to fit their needs, offers a great deal for these students. It is a subject of great complexity, where evidence reveals patterns that offer clues to the nature of the natural world. It is a subject based on model-building and theory-construction, but always answerable to testing against nature. That is, it is a subject that demands high levels of thinking skills, and repays careful and extended engagement with the subject matter.

This type of course also offers considerable opportunities for building in the application of mathematics, something which some commentators (such as SCORE, the umbrella organisation: Science COmmunity Representing Education) feel is largely missing from many secondary courses. Chemistry offers much scope for careful quantitative practical work, as well as many opportunities for data handling and mathematical modelling. As one example, patterns in ionisation energies are normally only studied post-secondary, but offer some excellent opportunities for graphing complex data that can be linked with learning about the periodic table (and basic models of atomic structure).

So there is room for offering *some* students a chemistry course that is more traditional in terms of being primarily based around the structure of the discilpine (periods, groups, classes of organic compound) to reflect a subject that has a strong theoretical aspect as well as having many important real-world applications. However, even for these students, it should be remembered that there is little value in attempting to offer a comprehensive survey of chemistry, as it is far too vast a subject to do that well in the available time, and whatever particular chemistry is later needed, can always be studied in post-secondary courses. Indeed, this group of learners will benefit most from the opportunity to study a small range of topics from different areas of chemistry, but in depth, and through learning approaches that engage higher-level thinking skills, and offer opportunities for extended laboratory work, problem-solving, and authentic projects what can be reported later to peers or wider audiences. Such a course will better meet the intellectual needs of this group of students, and by showing something of the nature of chemistry as a science may encourage many to pursue the subject further.

Last words

Ultimately, then, there are good reasons to consider chemistry a key part of the science education of all students, and a range of approaches that can be taken to develop diverse courses in secondary chemistry suitable for different groups of students. It should be an aim to allow *all* students to appreciate the fundamental principles of the subject: to understand something of the nature of chemical substances and reactions, including our submicroscopic theoretical models – so providing a foundation for later learning (whether in formal courses, or through informal learning in response to personal interests and needs).

We should not be precious about wishing to teach our favourite specific areas of chemistry when these do not seem relevant to our students, but should be open to context-based approaches, foregrounding the nature of science, and addressing socio-scientific issues which are often better able to engage student interest. Difficult decisions will need to be made over the value of having a distinct 'chemistry' strand within science education – as some groups of students may be better served by a more integrated approach to science, but where the disciplinary source of different topics are ideas are identified. Some students, if a minority, will gain more from approaches which foreground the theoretical structure of chemistry as a scientific discipline, and require deep engagement with some of the many challenging concepts the subject offers. Most students will appreciate some element of choice, both in terms of having an input into the kind of science courses they follow and in being given a selection of alternative activities on some occasions. Most students will also benefit from some variety in their learning of chemistry regardless of whether their course primarily has a focus on applications, science in society or disciplinary structure. Luckily for the chemistry teacher, as the present handbook demonstrates, chemistry is a subject which offers a great deal of variety in both its content, and the way it can be taught.

Other resources:

Teaching about the nature of science:

A companion volume in this series focuses on teaching about the nature of science: Vanessa Kind and Per Morten Kind (2008) Teaching secondary how science works. London: Hodder Murray

The role of chemistry in a sustainable world

The book A Healthy, Wealthy, Sustainable World by John Emsley (2010), published by RSC publishing offers a very readable account of how chemistry is developing the materials we need to maintain and improve our living standards in more sustainable ways. A downloadable article on this topic, may be found at

http://www.rsc.org/Education/EiC/issues/2011September/healthywealthsustainableworld.asp

Teaching science in context:

A report on context-based science teaching is available from the University of York's website: Bennett, J. (2005). Bringing science to life: the research evidence on teaching science in context. York: University of York, Department of Educational Studies. (Available at:

http://www.york.ac.uk/media/educationalstudies/documents/research/Contextsbooklet.pdf)

Teaching socio-scientific issues:

SATIS (Science and Technology in Society) is a series of resources first produced by the Association for Science Education in the 1980s and 1990s. Many of these have been updated, and are freely available from the website http://www.satisrevisited.co.uk/

Teaching chemistry to the gifted:

Advice on teaching the most able students in science classes is given in Taber, K. S. (Ed.). (2007). *Science Education for Gifted Learners*. London: Routledge.

An article on how chemistry is a suitable subject for challenging the most able is freely available on the web: Taber, K. S. (2010). Challenging gifted learners: general principles for science educators; and exemplification in the context of teaching chemistry. *Science Education International, 21*(1), 5-30 (available at www.icaseonline.net/sei/march2010/p2.pdf)

Mathematics in chemistry and general support for chemistry teachers

The magazine *Education In Chemistry* (published by the Royal Society of Chemistry) has published a series on teaching mathematics for chemistry. It also publishes a wide range of news, reviews and articles of relevance to teaching chemistry at school (as well as college and undergraduate) level. The magazine website is at: http://www.rsc.org/education/eic/

Chemistry Education Research and Practice is a free-access research journal published by the Royal Society of Chemistry, which publishes a wide range of articles about learning and teaching in chemistry. Articles can be accessed through the website at: http://pubs.rsc.org/en/journals/journalissues/rp