Perspective

Raising the Status of Chemistry Education

William S. Price[a] and John O. Hill[b]

[a]*Nanotechnology Group, College of Science, Technology and Environment, University of Western Sydney, Penrith South, NSW 1797, Australia*
e-mail: w.price@uws.edu.au

[b]*La Trobe University, Wodonga, Victoria 3690, Australia*
e-mail: j.hill@latrobe.edu.au

Abstract
Despite being one of the cornerstones of science, technology and industry, and forming the foundations of the life sciences, it is apparent that chemistry is in decline internationally as an 'enabling science'. This paper, primarily using Australia as an example, explores the components of the problem, identifies the challenges involved in addressing these, and proposes some solutions, which relate to raising the status of chemistry education. Chemistry as a discipline has a bright future – providing that chemistry education can more effectively convey the truly broad scope and integral position of chemistry, not only among the sciences, but also in daily life and human activities in general. This will entail improving its public perception, altering and restructuring the curriculum from primary school through to and including university to emphasize the multidisciplinary nature of chemistry and how the individual chemistry units of study integrate together and with other disciplines, and highlighting the ultimate outcomes and career opportunities.

Introduction

Australia has publicly announced that one of its principal aims in the 21st century is to achieve 'knowledge nation status', and it is intuitively obvious that technical (scientific) knowledge is a major component of this somewhat abstract ambition. However, it is also obvious that science education in Australia and chemical education in particular, both in the secondary school sector and in the tertiary sector, is failing to produce sufficient numbers of professionally trained scientists, especially chemists to feed and sustain the knowledge nation concept.[1] Indeed, as noted by Roberts,[2] if insufficient graduates are produced domestically, then suitable graduates will either be obtained from overseas or research and production will be moved abroad. Hence, at the commencement of the 21st. century, Australia is in the midst of a dilemma – how to achieve 'knowledge nation' status when the mechanisms for achieving sufficient numbers of professionally trained scientists (chemists in particular) are in crisis.

Chemistry education as an academic discipline is in decline internationally – although the actual form of the decline varies with the region. Hill and Cross[3] sounded the alarm in 2001 with an article in the '*Education Age*' entitled 'Australian Chemistry in Crisis'. Recently, similar alarms have been sounded in the UK (e.g.,[2, 4-8]). Chemistry is also in decline in the Japanese University sector (e.g.,[9]) and the US and European Universities are experiencing declining (chemistry) staff/student ratios along with concomitant funding constraints.[10] However, these trends appear to be most acute in Australia. The decline in Year 1 University science students electing to study chemistry as a major was the subject of an important statement by the Royal Australian Chemical Institute in 2001[11] with the theme 'Rebuilding the Enabling Sciences - Reclaiming the key to unlock the Nation's Potential'. This was a joint statement by the professional institutes of the 'enabling sciences' in Australia - physics, chemistry, mathematics and engineering. It was directed at the Federal Government and it defined the problem thus: "*if the current rate of university (science) staff losses continues, there will be no significant enabling science education base to support technological innovation by 2020 and if the current rate (of decline) of secondary school participation in the enabling sciences continues, these sciences will disappear from the school curriculum by 2020*". Statistical data were provided to support these alarming claims.[12] This statement clearly indicates the depth of the present crisis in Australian (chemical) education. However, before solutions can be found to address the crisis, it is necessary to understand that the problem is multi-faceted, and to identify some of the contributing factors that have progressively elevated the problem to crisis proportions.

Although the prestige of chemistry as a discipline is slipping in many countries, there are differences between the countries. In Australia, for example, it is shown by the decrease in the size of chemistry departments; in the UK, rather than individual chemistry departments shrinking, it is the number of chemistry departments that are decreasing[5] and even the future of chemistry at King's College London is in doubt[13] (in fact intake there has now been halted). The number of chemistry students in the UK is declining both in absolute numbers and as a proportion of the overall number of students in higher education; the increase in the number of students studying non-science disciplines shows the university sector to be buoyant, though not in chemistry.[5]

Finally, Holman[14] has succinctly summarised the wider benefits of overcoming the problem of a global decline of the enabling sciences. Science education is justified for several reasons: utilitarian – it is useful in everyday life, economic – the world needs trained scientists and engineers, democratic – everyone needs some knowledge/understanding of science to be able to participate in public policy debates and cultural – science is part of our modern culture and is worth studying for its own sake. Chemistry is inherently always present and will always be taught in some form, but from a scientific viewpoint if knowledge is to be generated, efficiently disseminated, and time-wasting re-invention avoided, chemistry as a discipline needs to keep its underlying organization. This paper attempts to examine the problem, including international comparisons, identify the challenges and provide some solutions, with particular emphasis on attracting students back to chemistry. To gain an international perspective, feedback was sought and received from a number of high-ranking chemists in Japan (NB, also one of us, WSP, spent nine years in Japan, three as a Professor of Chemistry at Tokyo Metropolitan University), Sweden, US and the UK. This paper, although independent in origin, complements a recent paper by Wallace.[8]

The Origins of the Problem

We believe that the core of the problem is that chemistry has lost its identity and (perceived) purpose and consequently has slipped from being an elite and key science to a subservient one with non-clear cut career prospects. Since the problem of a decline in the image and emphasis of chemistry is multi-faceted, it is evident that the solution must also be multi-faceted. Perhaps the major challenge is to separate and distinguish it from other disciplines and yet to emphasize its foundation and enabling position in them. In addition, the image of chemistry needs to be modernized from the traditional stereotyped images of chemists. We believe that the present funding hardships are a consequence of the low public perception, and not the reverse. Thus the challenge is to achieve the following aims: (1) restore the public image of chemistry, (2) attract undergraduates, (3) teach chemistry in a coherent and cohesive manner, (4) retain undergraduates through to postgraduate study, and (5) to clearly define and enhance career prospects. The origins of the problem can somewhat loosely be classified under the following headings:

Lack of Identity, Public Perception and Early Education

One reason for the decline of chemistry in Australia is that, due to its very ubiquity,[15] chemistry has developed an identity problem. 'Chemistry' is perceived as an umbrella-like term instead of being an entity itself. Consequently, except for being able to state that 'chemistry looks at the world at the molecular level', it is in reality very difficult to delineate chemistry from other sciences, or more importantly, recognize that chemistry lies at the heart of other disciplines like forensic medicine or pharmacy (e.g., see[16, 17]). Further, even though the applications of chemistry might appear 'macroscopic' and to relate to the real world, the real work of the chemist is entirely focussed at the molecular level. And, as illustrated by Bard,[18] it can take a very long time for a fundamental research finding to develop into a useful application. Thus, for example, in contrast to medicine, genetic engineering and the biological sciences generally, the importance of chemistry and its positive societal impacts, although at least as great, are not so readily perceived and appreciated. Although it is difficult to imagine a more exciting discipline to work in,[19] the lack of general public recognition results in two serious consequences. First, chemistry loses its relevance in the eyes of the general public, and more particularly, students only really begin to understand the importance and enabling nature of chemistry education among the sciences after they have entered university (assuming that they have chosen to study some chemistry) – often too late to reverse their thoughts on a career path. The second consequence is that, although chemistry does lead to a myriad of career opportunities, this may not be immediately obvious from the job titles. This consequence is becoming more serious in Australia, since university fees are steadily increasing, and present day students are much more demanding of university qualifications that appear to lead more directly to clearly defined employment.

The low public perception is self-propagating, as has been realized in Japan where most university graduates are non-science graduates.[20] Consequently, they are unlikely to encourage their children to study science, and particularly chemistry, at the tertiary level. Surveys have revealed that while 70% of Japanese primary school students and 50% of junior high school students (years 7 - 9) are interested in science, only 30% of senior high school students (years 10-12) share that interest.[20] A further reason for this decline, at least in the case of Japan, can be found in the nature of the entrance examinations to high school, as they contain little chemistry and the textbooks are often uninteresting.[20]

The lack of identity of and general ignorance about chemistry has also lead to positive, chemically-based scientific advances being attributed to other disciplines; for example, newly developed anti-cancer drugs are unlikely to be presented by the media as triumphs for synthetic chemistry. In fact, chemistry has gained negative connotations, with the public blaming chemistry for the pollution evils of the world. The situation is made worse by adverse media exposure of environmental degradation portrayed as 'chemical irresponsibility' and by confusion in the public sector over the terms 'chemist' and 'pharmacist'.

Mathematics

Apart from solving particular problems, the true aim of science is to gain a sufficient understanding thereof so that it is possible to predict scientific outcomes. Thus, research can be perceived as a cyclical process, involving observation, pattern recognition, mathematical modelling, designing more cogent experiments based on the models, and further observation. With sufficient understanding it is possible to make transitions from 'macroscopic' to 'microscopic' and vice versa. Mathematics is at the heart of this process. We note Sir John Pople's Nobel Prize citation which read *"…we celebrate the fact that mathematics has invaded chemistry, that by means of theoretical calculations we can predict a large variety of chemical phenomena*".[21, 22] Hence, the present trend involving the progressive simplification or 'dumbing down' of the university Chemistry 1 course – especially, the de-emphasising of mathematical/theoretical principles[1] is of great concern. This results in the loss of some of the most important tools that chemists need to use in modelling processes. It is instructive to delve into the contents of some of yesteryear's chemically oriented mathematics texts,[23, 24] and mathematically more demanding chemistry texts.[25] These books are full of the beauty, elegance and *efficiency* of applying mathematical principles to almost all areas of chemistry. The problem is that mathematics is not perceived as a tool of chemistry. Indeed, the mathematical content of chemistry is seen as a significant turn off factor and is one of the prime reasons that chemistry is seen as a hard subject. Consequently, other seemingly more qualitative and less mathematical sciences have become more attractive. Students, who adopt this selection principle, use sophisticated software to rationalise phenomena, but do not understand how the interpretation is produced - it is 'black box' learning! Indeed, the process becomes self-propagating with employers being equally ignorant and thus perceiving little need for mathematical skills.[26] A significant challenge is to re-emphasise the importance of mathematics in chemical education at all levels, as the de-emphasising of mathematics is in reality detrimental to all of the quantitative sciences.

Loss of its Enabling Role in the Sciences and Attrition to Other Subjects

In searching for ways to increase the appeal of chemistry, in addition to lack of recognition, it is necessary to address the sustainability of chemistry as a central science discipline. A discipline can survive, at least in the short to medium term, by obviating the 'hard parts'. As chemistry is taught less comprehensively and coherently it necessarily loses its enabling role in the sciences. For example, when chemistry is only taught as a service course, some aspects of chemistry that are crucial to a career in chemistry, but which are not believed to be crucial to less quantitative disciplines, are omitted. Although it is to the detriment of the other disciplines as chemistry loses its enabling role, it is ironic that some of the other disciplines therefore become more attractive. Fragmentation of the teaching of chemistry as a discipline may also have the negative effect of some areas of chemistry having to be reinvented when the need for them is recognized.

Although similar arguments could be made for other disciplines, such as materials science, due to familiarity (one of us, WSP obtained his PhD in Physical Biochemistry) we use the discipline of biochemistry to illustrate the problems that arise if chemistry is not taught cohesively and comprehensively. Biochemistry can be viewed as a melding of biology with chemistry, originating from the need to understand and to explain biological phenomena at the molecular level. All biochemical techniques are intrinsically chemical in nature – although many biochemistry students would not realize this. Many disciplines, including biochemistry, use NMR (or MRI) routinely, but often the basic principles of this sophisticated spectroscopic technique are glossed over. The absence of a solid chemical (and physical) background greatly impedes the development and application of NMR techniques. But perhaps more importantly, this absence leaves the user less able to separate real from artifactual observations. Ultimately, the other disciplines are also losers when chemistry is not taught cohesively and the outcome of such omissions of key principles is that so-called ‘trained scientists’ become closer to trained technicians. It is a significant challenge to reverse this trend.

We would also note that biochemistry has developed rapidly into a stand-alone prestigious science, whilst the importance of chemistry as an enabling science is waning. Part of the reason for this is that in many chemistry departments the subdisciplines are organized along traditional lines (i.e., organic, physical, inorganic) and thus the enabling role of chemistry in the biological sciences is not emphasized. Indeed, in chemistry departments the term ‘biological chemistry’ is often narrowly specified as encompassing only the organic chemistry of biologically active compounds. We believe that biological chemistry is much more than this and that a more complete description that could be conveyed to students is ‘the chemistry of biologically-ordered structures that ultimately lead to some form of self-replication’. Thus, biological chemistry encompasses and requires elements from all of the traditional sub-disciplines of chemistry. Hence, irrespective of whether chemistry is taught in a Chemistry department or not, what is important is that it is taught in a comprehensive manner and that the significance and integration of the individual units is explained.

Chemistry 1 Courses

Although the number of students in the University ‘Chemistry 1’ courses in Australia has remained reasonably constant owing to the service element of the course, fewer Year 1 University science students are electing to study chemistry as a major or view chemistry as a career opportunity or continue to undertake study for a higher degree in the discipline. Although the academic community blames the secondary school sector for not encouraging students to study science at the higher school certificate level, it is also useful to look at this from a societal perspective (as noted above). Chemistry 1 courses need to be designed to enthuse science students to ‘convert to chemistry’. Cole et al[27] have highlighted some of the reasons for the flight from chemistry: students perceive little relevance of core chemistry to the real world; syllabuses are overcrowded, leading to shallow learning and little time to incorporate exciting cutting edge chemistry; students feel that a large body of knowledge has to be absorbed before they can make a worthwhile contribution; students perceive that knowledge is more important than the acquisition of transferable skills; students have difficulty making connections between the sub-disciplines of chemistry (which tend to be taught separately); the link between practical work and theory is often less than obvious; not enough emphasis is given to the social aspects of chemistry and Chemistry 1 students have inadequate levels of mathematical skills to cope with some aspects of the course. Especially, without incentive and justification of the incorporation of the component units, chemistry (esp. the mathematical content) seems to be a hard subject.[4] This also impacts on the number of students who will choose to continue on to higher degree.

Career Prospects

Although a high school student has certainly been exposed to some chemistry, it is likely that, apart from their high school chemistry teacher, students do not have a strong feeling for what a chemist actually does (as noted by Wallace,[8] this source of inspiration may be further compromised if the ‘chemistry teacher’ is not a chemist). In fact, due to the enormous scope of chemistry, it is particularly difficult to describe succinctly what a chemist does. This situation is in complete contradistinction to other professions, for example, a physician or dentist. Further, even at the tertiary level, the majority of chemistry education is conducted by academics who, statistically, only represent the career of a small proportion of chemical graduates. Even for those who opt for academia, the allure of an academic career in chemistry is tarnished by the current economic climate and government policies resulting in the real and perceived need to spend an inordinate amount of time to raise funds to conduct research.[18] So students have only limited exposure to the types of careers available, with industrial careers receiving the least exposure. Thus the final challenge is to make chemistry a solid choice for a career and this necessarily involves some restructuring of courses to emphasize the outcomes.

Solutions

The essence of the solution is that public perception of chemistry needs to be enhanced. Obviously this would benefit from changes in primary and secondary school curricula. Similarly, increases in the salaries that science graduates can expect would also enhance its perception - but this is not the cause of the problem. The solutions presented here are mainly confined to what can be implemented inside the university setting. We also pay particular attention to retaining students on to higher degrees.

Experiences Prior to University and Public Perception

As noted above, most school children and many high school children have a strong interest in science but this popularity gradually wanes. This is of particular concern since it is the demand at the primary level that successively determines the secondary school and tertiary curricula and influences the choice of entry to university. Thus, not only is it important to introduce scientific concepts early in the educational system, but it is also imperative to maintain the level of interest. The chemical societies (e.g., RSC and RACI) would appear to be best placed to produce and distribute captivating literature and promotional material suitable for primary and secondary schools, and in Years 10, 11 and 12 organising visits to the chemical industry, companies producing everyday (chemical) products and academia. These initiatives will address the issue of 'what chemists do'. A detailed discussion of some approaches for increasing the public awareness of chemistry has recently been published.[28] Stressing the scientific method and the central role of mathematics would also greatly assist the attraction of students to chemistry and the physical sciences by alleviating the mathematical turn-off factor and this is covered in more detail below.

Chemistry departments could also try to cultivate links with the public, but especially with schools,[29] including teachers and careers advisors. Some of the strategies applied in Japan have included universities grouping together to organize a major chemical exhibition in Tokyo.[20] The purpose of the exhibition was to attract students and to increase the interest of the public (including the students' parents). Japan has also had the benefit of three recent Nobel Prizes in chemistry, which has helped in maintaining chemistry enrolments. Further, some universities have organized programmes in which chemistry staff members would go and give lectures, and perhaps more importantly, demonstrations at local high schools and junior high schools. In the case of Tokyo Metropolitan University, something like 20-30 such lecture/demonstrations were held in a year and it was deemed successful as the number of applicants to study chemistry did increase. Also, about 200 High School students come to Tokyo Metropolitan University for a day every year to be involved in chemistry. Similar ideas are being tried in the UK with the Science and Engineering Ambassadors initiative.[30] With such efforts, more high school students are likely to select chemistry at the tertiary level.

It is also necessary to 'clean-up' the traditional image of chemistry and to emphasise chemical safety more explicitly. The viewpoint that chemists are trained to handle chemicals safely must be widely promoted so that it becomes apparent that chemistry is neither a dirty nor a dangerous profession. The major advances in Green Chemistry in Australia[31] certainly contribute to an acceleration of the required chemical image change.

Attracting Students to Tertiary Chemistry and Student Retention

Research and Research-led Teaching

A significant attraction for students contemplating the study of chemistry and an impetus for continuing to study chemistry as a major is the intellectual heritage and research strength of the university and chemistry department in question. This is extremely important, as many students value the kudos associated with an institution with a strong research standing – even if they do not intend to go on to a higher degree. Indeed, the most sought after universities are without exception those where research drives the culture.[32] As noted by Callaghan, "*universities provide a unique environment because they combine teaching and research, and sometimes it is hard to tell which is which. And that confusion is precisely the ideal state of affairs*".[32] Generally, students in 1st year chemistry do not have a clear idea of what research is being conducted by their lecturers and the chemistry taught in Chemistry 1 is not 'cutting edge' – although of course it forms indispensable background knowledge. A series of short lectures given by different members of staff on their research, with some emphasis on how different elements of the chemistry curriculum integrate together to make their research possible, would increase enthusiasm for continuing on with chemistry. Studying individual chemistry units with some kind of goal in mind greatly increases their appeal. Callaghan has eloquently explained the benefits of research-led teaching under the headings of 'ownership', 'authorship and 'apprenticeship'.[33] In his thesis, only someone who has made scientific discoveries can convey a sense of intellectual *ownership* to what they teach. Similarly, a lecturer who is a published *author* can convey critical judgement to the students because he knows how fragile knowledge is. The final element is *apprenticeship* in which the students learn alongside their teacher in a mutual dialogue, with the ultimate aim for the apprentice to exceed the master. Thus the combination of teaching and research provides a powerful means of attracting, retaining and inspiring students.

Mathematics

The predictive power, beauty and economy of physical approaches needs to be emphasised in the Chemistry 1 course so that students do not see mathematics as irrelevant or unnecessary in chemistry. It is necessary to indicate in the Chemistry 1 course and earlier, the essentials of the scientific method and that mathematics in chemistry is an enrichment factor that qualifies chemistry as an elite, quantitative science and sets it apart from some of the more qualitative areas of, for example, the biological sciences. In addition to better press and public perception, the latter are sometimes viewed as more attractive by university students because of their lesser mathematical content. For example, biochemistry is often perceived by students as non-mathematical chemistry and therefore preferable. It is rather ironic, however, that mathematics is really required for many areas of biochemistry (e.g., enzyme kinetics, protein aggregation, and drug interactions) and in other biological sciences. Nevertheless, it should be emphasized that such is the scope of chemistry that if the student really dislikes or is unable to cope with much mathematics it is still possible to specialise in chemistry in areas with low mathematical requirements.[4] We believe the allure of chemistry, and indeed the other physical sciences, at university would be increased if high school mathematics curricula were amended to emphasize the inherent links and usefulness to the sciences. If students could be more enthused to study mathematics, one of the turn-off factors to studying chemistry would be eliminated.

Cohesively Teaching Chemistry and Minimizing Attrition to the Other Sciences

As chemistry is less cohesively and comprehensively taught, many aspects of chemistry are necessarily taught by and assimilated into (some might say hijacked by) other disciplines (e.g., biochemistry, materials science) and these other disciplines separate out and gain in stature. Although, ideally, it is nice to imagine that all of chemistry is taught in a chemistry department, the most crucial aspect is that chemistry should be taught in a (reasonably) comprehensive manner since the solution to most real world chemistry problems require more than one facet of chemistry. For example, designing medicinal drugs and understanding their binding to protein receptors requires knowledge of many areas of chemistry ranging from organic chemistry to computational chemistry and thermodynamics.[34, 35] Similarly, thermodynamics, organic chemistry and inorganic chemistry are needed to understand bioenergetics, including transmembrane ion transport and respiratory chains.[36, 37] Thus, a broad background in chemistry education is important so that chemistry does not lose its enabling role.

As an example of what can be done, and again taking the biological sciences as case in point, a strategy for lowering the attrition to the biological sciences would be to create a 'Biological Chemistry Sub-Discipline' with a broad scope within a chemistry school. This may not only provide a means of enhancing research funding opportunities, but it also addresses the ignorance of chemistry traditionally held by Year 1 science students about the enabling nature of chemistry and its integral role in biology and biochemistry. Such students need to recognise that these interfaces between these disciplines are flexible and porous. This presents an opportunity here to capitalise on the fact that of these three disciplines, chemistry is the most flexible and has the widest scope of topics. Chemists need to stress at every opportunity that they can tackle and solve biological problems at the molecular level – where the core interest is focused. An equally important issue to stress is that there are no realistic boundaries between the sciences. Indeed, chemistry has spawned many of the ‘new’ sciences and many of the major advances in science have emerged from science interface research. Chemistry is well placed to underpin such research because of its multi-disciplinary platform. It also needs to be emphasised that the way to tackle a complicated biological system is not to tackle the problem directly and holistically, but to do so via a series of well-chosen model systems of increasing complexity. Model systems always lead back to chemical counterparts.

A further possible strategy for retaining students in a chemistry main stream is to develop a biological chemistry project (or centre) to which all research-active members of the chemistry department can contribute, thus harnessing the full talent mix of the department. Many biological problems benefit from a concerted research input and the output in terms of results, will be greater than the sum of the individual contributions. Such a large-scale project would provide a ‘biological face’ to the chemistry department. The potential for such a research project to attract funding more successfully than any one contributing member, is an added advantage of such an initiative.

Career Prospects, Industry, Interdisciplinary Science and Rebadging

It is becoming increasingly clear that it is progressively more difficult to retain science students into Years 2 and 3 of the traditional chemistry major bachelors degree. Chemistry 1 students need to be given more information on the sorts of careers that are ultimately available to them and what combinations of units are most appropriate for these. It is necessary to identify the most able science students in the Chemistry 1 course and expose them to the wide and diverse range of career opportunities that a qualification in chemistry can lead to and the rewards that such careers offer, apart from the purely financial. It is necessary to emphasise that the traditional ‘bubble and boil’ image of chemistry, whilst appealing to many, is not a realistic representation of the whole of professional chemistry and leads to very narrow perceptions of what careers are available to chemistry graduates. Indeed, many professional chemists may not even come into contact with chemicals – the involvement of theoretical chemists with drug design is but one example. One means of making chemistry more attractive is to emphasize its relevance and career prospects by 'rebadging' and grouping some of the courses with respect to some target area of application. For example, studying thermodynamics and colloid chemistry are crucial components of an undergraduate degree in chemistry, but someone embarking on a chemistry degree does not always understand their importance. However, they may be made more palatable and attractive to students if included as strands of a course on 'chemical biotechnology'. Similarly, nanotechnology is now widely publicized and chemistry is at the heart of this.[38]

One of the strengths of chemistry is its ability to contribute to interdisciplinary research; in fact some, mainly younger, universities do not even have a distinct chemistry department. Indeed, it has been noted that the development of interdisciplinary degrees may help to solve some of the problems facing chemistry education.[2] Nevertheless, what is important is not the name of the department, but that chemistry as a discipline is still effectively taught. The setting up of interdisciplinary research centres has the advantages not only of attracting money from industry, but also the emphasizing of the industrial career paths that chemistry can lead to that would not otherwise be apparent to undergraduates. Although, as is well known, the setting up of such ventures is non-trivial and fraught with difficulties; it is recognised as means of making up financial shortfalls – even at Oxford University.[10]

The chemical industry sometimes blames the academic community for not giving chemistry courses more of an applied emphasis. Thus, just as it is necessary to promote strong links between chemistry departments and schools, it is also necessary to promote stronger links with industry and to invite industrial leaders and managers to visit chemistry departments. Interestingly, in Japan companies sponsor the Chemical Society of Japan (CSJ) as corporate members. As such, they have access to CSJ journals and, depending on the level of company sponsorship, a number of the company members can attend the annual CSJ meeting with the same conference fee as normal member although they are unable to make presentations. Although it does present some financial problem to the CSJ, this corporate mechanism constitutes the main link between academia and industry.

Recapitulation

The ubiquity of chemistry guarantees that chemical education will always have a central, commanding position amongst the sciences. The problem is that the public does not necessarily see this as being such. This perspective has explored some of the means that can be taken to increase the public perception of the value of chemical education so that chemistry will be an academic pursuit of choice and not just the prerequisite for something else, and maintain the cohesiveness of the teaching of chemistry so that it can fulfil and retain its enabling role.

References

1) J.O. Hill and R.T. Cross, *A Report on a Comprehensive Review of the Year 1 Chemistry Course in Australian Universities*; La Trobe University: Wodonga, 2001.
2) K. Roberts, *Educ. Chem.*, 2004, **41**, 2.
3) R. Cross and J. Hill, *Opinion*, *The Education Age*, 2001, 28 March.
4) L. Willcocks, *Why is Chemistry so Sexy? Varsity* 2001. http://www.varsity.cam.ac.uk/8025694e0073cfeb/pages/11102001_WhyisChemistry.html
5) S.W. Breuer, *U. Chem. Ed.*, 2002, **6**, 13.
6) M. Freemantle, *C. & E. News*, 2002, **80**, 31.
7) J. Naismith, *Chem. Brit.*, 2002, **38**, 3.
8) R.G. Wallace, *Chem. Educ. Res. Pract.*, 2004, **4**, 83.
9) H. Ogino, *Bunseki*, 1996, **257**, 329.
10) M. Jacobs, *C. & E. News*, 2002, **80**, 5.
11) National Initiatives in Education. A joint statement by Australian Institute of Physics (AIP), Royal Australian Chemical Institute (RACI), Australian Mathematical Sciences Council, Institution of Engineers Australia (IEAust), 2001. http://www.aip.org.au/initiative2001/
12) D.J. Evans, *Chem. in Australia*, 2001, **68**, 17.
13) D. Giachardi, *Chem. Brit.*, 2003, **39**, 3.
14) J. Holman, *Educ. Chem.*, 2001, **38**, 10.
15) B.K. Selinger, *Chemistry in the Market Place*; 5th ed., Allen & Unwin: Sydney, 1999.
16) P.N. Goodfellow, *Chem. Brit.*, 2002, **38**, 3.
17) W.S. Price, *Aust. J. Chem.*, 2003, **56**, 855.
18) A.J. Bard, *C. & E. News*, 2002, **80**, 44.
19) M. Trau, *Aust. J. Chem.*, 2001, **54**, 549.
20) I. Ikemoto, Tokyo Metropolitan University, Personal communication; 2003.
21) The Nobel Prize in Chemistry, 1998. http://www.nobel.se/chemistry/laureates/1998/presentation-speech.html
22) P. Wright, *Sir John Pople - Mathematician who applied his brilliance to chemistry, The Guardian*, 2004. http://www.guardian.co.uk/obituaries/story/0,3604,1172894,00.html
23) H. Margenau and G.M. Murphy, *The Mathematics of Physics and Chemistry*; D. Van Nostrand: New Jersey, 1956.

24) C.L. Perrin, *Mathematics for Chemists*; Wiley: New York, 1970.
25) A.G. Marshall, *Biophysical Chemistry Principles, Techniques, and Applications*; Wiley: New York, 1978.
26) P.C. Yates, *U. Chem. Ed.*, 2002, **6**, 17.
27) M. Cole, R. Janes, M. McLean and G. Nicholas, *Educ. Chem.*, 1998, **35**, 56.
28) R. Stevenson, *Chem. Brit.*, 2003, **39**, 20.
29) M. Berry, *Chem. Brit.*, 2002, **38**, 3.
30) Scientists in Schools, *Chem. Brit.*, 2002, **38**, 58.
31) Centre for Green Chemistry, 2003. http://web.chem.monash.edu.au/greenchem/
32) P. T. Callaghan, Unpublished public lecture given at Victoria University of Wellington; 2002.
33) Callaghan, P., Ownership, Authorship and Apprenticeship and the Research Teaching Nexus, in *Towards an Understanding of the Interdependence of Research and Teaching*, S. Paewai, G. Suddaby, Eds., Massey University: Palmerston North, 2000. http://quality.massey.ac.nz/download/MUIRT.pdf
34) J. Wyman and S.J. Gill, *Binding and Linkage - Functional Chemistry of Biological Macromolecules*; University Science Books: Mill Valley, 1990.
35) K.E. Van Holde, W.C. Johnson and P.S. Ho, *Principles of Physical Biochemistry*; Prentice Hall: New Jersey, 1998.
36) D.A. Phipps, *Metals and Metabolism*; Clarendon Press: Oxford, 1976.
37) D.G. Nicholls, *Bioenergetics*; Academic Press: London, 1982.
38) M. Wilson, K. Kannangara, G. Smith, M. Simmons and B. Raguse, *Nanotechnology: Basic Science and Emerging Technologies*; UNSW Press: Sydney, 2003.