SCIENTIFIC LITERACY
AND THE REFORM OF
SCIENCE EDUCATION IN
AUSTRALIA - A CHEMISTRY
PERSPECTIVE

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ABSTRACT

There is considerable qualitative and quantitative data to suggest that chemistry in Australia is in a state of decline. This trend has been in evidence for the last fifteen years and is most evident from a progressive decline in demand for tertiary chemistry courses over this period despite an overall increase in demand for science courses in Australian universities. There is quantitative evidence to suggest that Australia is experiencing a ‘skills shortage’ of ‘trained chemists’ to support the development and sustainability of the chemical industry and, perhaps more significantly, the proportion of chemistry graduates entering the teaching profession is also decreasing.

This thesis examines the reasons for this decline in the status of Australian chemistry by conducting a series of interviews with Heads of Departments of Chemistry in Australian universities to find out their concerns on this issue and, more specifically, to ascertain the actions that they are enacting to address the decline in demand for tertiary chemistry courses and the difficulty in retaining students in the chemistry major. This process also revealed numerous constraints, most significantly, financial constraints, that impede ‘change’ in the tertiary chemistry sector.

A comprehensive review of the state of chemical education in Australia at both the secondary and tertiary levels has been undertaken and it transpires that the lack of a significant chemical education culture in Australian universities possibly correlates with the lack of systematic reviews of the Chemistry 1 course curriculum over at least the past three decades. This deficiency suggests that such a lack of a well-entrenched chemical education culture in Australia is a major contributing factor to the demise of chemistry generally.

However, a comprehensive review of the state of international chemical education shows that whereas a decline in the status of chemistry has been experienced in the UK, the USA and to some extent, in Europe, major steps have been taken to address this trend with integrated strategies imposed by governments, schools, universities and, most significantly, chemistry professional societies. Thus, it appears that Australia is still in the midst of a ‘chemistry crisis’ and that urgent strategies need to be enacted to address this.
In this context and recognising that the foundation tertiary chemistry course has a major influence in attracting and retaining chemistry students and hence on the production of ‘trained chemists’, the major emphasis of this research is the development of a new curriculum framework for the tertiary Chemistry 1 course. This framework is based on a set of principles and is enabled by three contemporary educational theories which are integrated to form a distinctively balanced curriculum which emphasises the ‘simplicity of chemistry’ and includes the essential educational elements of ‘learning’ and also relates chemical principles and chemical phenomena to social responsibility outcomes. It is believed that this curriculum framework reveals the ‘excitement’ of contemporary chemistry together with its enabling features. Most significantly, it offers students a new, challenging and empowering chemistry learning experience. It is therefore concluded that this new Chemistry 1 curriculum framework has the potential to redress the decline of interest in chemistry at the tertiary level and hence contribute to addressing the increasing demand for ‘trained chemists’.
DECLARATION

This is to certify that

(i) this thesis comprises only my original work towards the PhD,
(ii) due acknowledgement has been made in the text to all other material used,
(iii) the thesis is less than 100,000 words (actual: 92,700) in length, exclusive of Tables, Bibliographies and Appendices,
(iv) the full transcript of the interviews with Chemistry Heads of Departments in Australian universities, included in Appendix 2, is unabridged and un-edited,
(v) the content of this thesis has not been submitted for the award of any other degree or diploma in any other tertiary institution.

J. O. Hill.
ACKNOWLEDGEMENTS

The genesis of this project evolved in 1997 when I was invited to join a delegation from the (then) Graduate School of Education at La Trobe University to Kunming, China. The delegation was led by Drs. Roger Cross and Ronald Price and the mission was to evaluate the methodologies and effectiveness of school science teaching in Yunnan Province via a Science Teacher Education and Training Conference at Yunnan Normal University. During this conference and particularly as a result of attending chemistry classes at local high schools, it became apparent that school science teaching in China was more effective than its counterpart in Australia in terms of enlivening students to study science. I was greatly impressed with the quality and methodology of teaching chemistry in Kunming secondary colleges and believed that this inevitably led to quality teaching of chemistry at Chinese universities so why was the opposite scenario prevalent in Australia?

I extend my sincerest gratitude to my supervisor Dr. Roger Cross, without whose constant support, encouragement, advice, vision and expert inclusive supervision this project would not have been completed. I am also most fortunate in having had critical advice, encouragement and support from Emeritus Professor Peter Fensham of Monash University, particularly in terms of his recommendation to publish a preliminary Chemistry 1 curriculum framework for comment by the professional chemistry fraternity.

I am indebted to my senior academic chemistry colleagues in universities around Australia who willingly and enthusiastically participated in the 1999 interview programme. Their collective responses constituted the principle data field for this research and inspired its progress.

I also acknowledge Professor Bill Price of the University of Western Sydney for his major input into the paper ‘Raising the status of chemical education’ (included in Appendix 4) and his consistent endorsement of the intrinsic value of this project.

(v)
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12. Fensham’s ‘Science for All’ vision: A chemistry perspective.
CHAPTER 1
INTRODUCTION

1.1 RATIONALE FOR THE RESEARCH

This project is a tapestry of many interwoven themes. When this project began in 1998 there was mounting concern among the Australian academic chemistry community about the continuing decline in student intake into the chemistry major degree, increasing student/staff ratios in university chemistry departments, declining departmental operating budgets and the consequential scaling down of these by amalgamation or absorption into other science departments especially biology and, perhaps of most significance, the perception that chemistry was losing its status and prestige in university science faculties.

It was relevant to find out in 1998 whether such a demise of chemistry phenomenon was unique to Australia or whether this was an international problem. There was some evidence to suggest that similar problems with respect to ‘chemistry sustainability’ were being experienced in the UK and in Europe whereas there was little evidence to suggest that this phenomenon had been experienced in the US. The author had spent four years at the National University of Singapore in the early 1990’s and from his observation chemistry in Singapore and in South East Asia in general, was thriving.

Hence, the initial question was ‘Why does Australia have this problem’. Anecdotal evidence from the chemistry professional community suggested that the ‘cause’ of declining student interest in chemistry at the tertiary level was due to changes in the secondary school chemistry ‘standards’ had fallen since new curricula were introduced. Put simply – the blame was firmly attributed to the teaching of chemistry at the secondary level and the appropriateness of the associated assessment procedures. It was believed that the decline in students electing to study science in Years 11 to 12 which had been progressive over the previous decade was due to the new chemistry curricula being unattractive, somewhat obscure and too difficult with respect to the level of mathematical skills required. Those students who did study science to the senior level tended to select biology.
However, it was known that there had also been considerable reform of ‘secondary chemistry’ internationally, particularly in the UK via the introduction of a national curriculum and the Salters’ course. In the US, there had been major reform of ‘General Chemistry’ – particularly at 2-year Junior Colleges. However, both the UK and the US did not appear to have experienced the ‘chemistry demise’ phenomenon to the same extent as was apparent in Australia at the end of the 20th century.

It seemed logical to conclude that ‘secondary chemistry’ was not the only cause of the problem (if at all) and that in all probability, many factors were involved. This prompted questions about the quality of chemical education at both the secondary and tertiary levels. In 1998, there was much evidence to show that Australia lacks a chemical education culture whereas such a culture is nurtured in the US and in the UK by a range of strategies. Most notable of these is a strong interaction between the respective Chemical Societies (American Chemical Society, ACS and the Royal Society of Chemistry, RSC) and the teaching profession at both the secondary and tertiary level. Further, chemical education research is flourishing in both the US and the UK, as evidenced by the continued publication of chemical education journals of international standing (The Journal of Chemical Education and Education in Chemistry). Also, international Chemical Education conferences are regularly held in the US and in the UK which include participants from the school and chemical industry sectors. Thus, in the US and the UK, there is a strong interaction between the school, university, chemical industry and professional society groups to nurture a strong chemical education culture. By contrast, the Chemical Education division of the Royal Australian Chemical Institute publishes a quality journal devoted to Chemical Education (The Australian Journal of Education in Chemistry) which has very limited readership and limited editions per annum. Chemical Education conferences in Australia are held biennially and participants do include science teachers but the scale of these does not match similar conferences organized by the ACS and RSC. Most significantly, the number of academic chemists who attend the Australian Chemical Education conferences is very small. Hence, it was reasonable to conclude in 1998 that chemical education in Australia was a significant part of the overall problem and this gave impetus to the rationale for the present project.

Another probable contributing problem was the general lack of interaction between the academic chemistry community and its industrial chemistry counterpart.
For decades, the chemical industry had tried unsuccessfully to be involved in the design of chemistry courses at the tertiary level so that an industrial chemistry ‘flavour’ was included to address the shortcoming of students ‘not knowing what real chemists do’. Over the years, the Royal Australian Chemical Institute (RACI) had made valiant attempts to bring these two professional chemistry communities into closer contact to mutual advantage but with little success – university chemistry departments largely ignored the gesture from the industrial chemistry community to be involved in the design of chemistry curricula. It appeared that the perceived demise of chemistry must in some way be related to this decidedly negative attribute and was certainly the cause of students not selecting chemistry because ‘it offered no obvious career in the future’.

An even more obvious factor was the poor public image of chemistry as the ‘cause of many evils’ in the world. This has come about by environmental disasters such as oil spills, nuclear explosions, chemical weapons such as Agent Orange, pesticide contamination of food, mercury contamination of fish, both causing genetic defects in new born babies and many other environmental disasters with a perceived chemical association – being given sensationalist and negative media coverage. The positive attributes of chemistry which effect almost every aspect of daily life, are rarely given such media coverage. Perhaps the main fault is with chemistry in that chemistry education at both the secondary and tertiary levels is not projecting the positives out to the community at large or revealing to the community that it has a responsibility towards it. Thus, neglect of the sociological dimension of chemistry at both the secondary and tertiary chemical educational levels may well be one of the major causes of its demise and account for student feedback that ‘chemistry is so obscure that it has little relevance to us’. If this is so, then perhaps it is chemical education in Australia that is in crisis and not chemistry per se. This assumption again added impetus to the rationale for the present project.

Yet another factor was evident from discussions with the academic chemistry community in 1998 that even the best science students who selected chemistry as a major at the tertiary level had considerable difficulty communicating in the language of chemistry and certainly had difficulty writing in chemical terms. It therefore appeared that the Year 11/12 school specialist chemistry courses were inadequate in teaching the culture and philosophy of chemistry. This was believed by some in the chemistry academic community to be due to a lack of inclusion of the history and
philosophy of chemistry in the secondary school chemistry curriculum. However, from the authors’ perspective, a similar argument could be levied against the traditional Chemistry 1 course that operated at that time. Thus, the senior school chemistry courses were criticized for not achieving a level of chemical literacy appropriate for the successful study of chemistry at the tertiary level. It was believed that because students had difficulty with the language of chemistry at the senior level, this was a major contributing factor to their inherent dislike of chemistry and their subsequent withdrawal from it. However, it was necessary to take a balanced view of this issue and ask what opportunities exist in the senior chemistry courses around the States for students to construct ideas using the language of chemistry and what constitutes the conceptual ability of students with respect to chemical concepts, particularly at the Year12/tertiary Year 1 interface? Further, once an acceptable level of chemical literacy has been achieved, what enrichment factors can be incorporated in the course to enhance this attribute? It was evident in 1998, that research into the learning and teaching of chemistry in Australia was extremely limited and initiatives such as multimedia simulations of chemical phenomena, real-life case learning studies, virtual laboratory exercises and undergraduate research were in the development/testing stage and not widespread in application either in the secondary or tertiary domains.

There were also major concerns among the chemistry community generally on the future of chemistry in the approaching new millennium. It was believed that chemistry needed to redefine its role in Australian science to ensure its survival. Its image as the central science needed to be reinforced at all levels and particularly in government levels so that not only science in Australia but also chemistry in Australia received considerably enhanced Federal Government funding for research and development. It was believed that chemistry could and should exert significant pressure on the direction of Australian science in the 21st century since it has a central role in and in fact ‘spawns’ many of the ‘new sciences’ that are emerging, such as environmental chemistry, green chemistry, biotechnology, genetic modification science and nanotechnology. It is not appreciated in Australia that chemistry epitomizes an ‘enabling science’. In this context, the RACI was severely criticized for not adequately publicizing the great benefits and enabling character of chemistry – not only to enhance the Australian economy but also to enhance the lifestyle and quality
of life of all Australians. This added another complex dimension to the proposed project.

Finally, and perhaps most significantly, in 1998, there was considerable anecdotal evidence among the chemistry academic community that the tertiary Chemistry 1 course needed major reform. This assertion was largely based on the fact that fewer students were selecting chemistry as a major and in general Chemistry 1 students were ‘switched off’ and disinterested. It was believed that Chemistry 1 needs to be made more interesting for students rather than insisting that they learn a very large number of seemingly disconnected ‘facts’. There was a related concern on how to retain students in the chemistry major and, more particularly, how to encourage the ‘best’ students in Chemistry 1 to continue in a ‘chemistry major’ rather than select ‘another’ science. It was also argued that the Chemistry 1 course is in the difficult position of having to appeal to the majority of the group who will not study chemistry beyond Year 1 and the minority who have selected chemistry as the major subject for study in their chosen degree course. This was perceived as a major dilemma in terms of defining a balanced curriculum for the Chemistry 1 course.

Although in 1998, there was widespread agreement among the Australian chemistry community that chemistry was in crisis, no general consensus appeared to exist as to the nature and cause of this crisis. Indeed, no agreement was forthcoming as to how to halt the decline in enrolments in tertiary chemistry courses or how to retain the best students in the chemistry major. It was however believed that the traditional Chemistry 1 course was a probable contributing factor to this crisis and that its ‘traditional’ content (which had been in existence for at least 3 decades) and style of delivery were defining features of its perceived demise. Hence, all this anecdotal discourse inherently defined a challenge – to undertake research into the causes of the perceived demise of chemistry in Australia and to select one of these causes for detailed examination with the expressed view of enacting change so as to remedy to some degree the present situation.

The next step was to decide which of the many perceived causes of the overall problem was the most urgent for detailed examination. Since, at the time, the author had more than 30 years of teaching experience in Chemistry 1 and a profound interest in attempting to remedy the decline of chemistry in Australia, it was decided to build a research project on the premise of a radical restructuring of the Chemistry 1 course. The author believed that the Chemistry 1 course, being experienced at the critical
Year 12/Year 1 interface has a major empowering influence on students and if this can be enhanced, the future of chemistry in Australia is proportionally enhanced and at least the intensity of the perceived crisis is reduced. However, it was appreciated that the proposed project could not simply be based on a new curriculum framework for this course since there were many related issues to be explored in the process. Paramount among these was an examination of the status of chemical education in Australia and internationally. Further, the developed curriculum needed to be informed by contemporary educational theory. It was realized above all that an effective new curriculum for the Chemistry 1 course had to overcome the many constraints inherent with the traditional curriculum, the most significant of which was the reluctance of the chemistry academic community to dispense with ‘well tried and tested’ teaching and learning methodologies associated with the traditional course which had ‘served the system’ well for so long such that Chemistry Departments across the country were proud of ‘their’ Chemistry 1 tradition. It was believed that ‘change’ to Chemistry 1 was an enforced casualty of a ‘contemporary belief system’. In other words, in 1998, the ultra-conservative Australian chemistry academic community only believed that Australian chemistry was in crisis because students were electing not to study it at University. The author believed that this was probably a delusion and thus the present project was born.

However, the rationale for the proposed project had to be based on some firm literature basis as well as on anecdotal perception of a ‘chemistry crisis.’ Four such literature sources were sufficient to mount a case for undertaking a research project on the status and future of the Chemistry 1 course in Australian Universities.

In 1993, the Royal Australian Chemical Institute (RACI) undertook a review of chemistry in Australia. Unfortunately, most of the review focused on the collective research effort and in particular, the interaction between university chemistry departments and the chemical industry but it also made an important recommendation to the tertiary teaching of chemistry at the tertiary level:

*Each chemistry department should establish a Departmental Advisory Committee with representatives drawn from industry, Government organizations, secondary schools, alumni and the tertiary sector. The committee should meet at least once a year and provide advice on a range of matters, including: the design and content of chemistry courses, development of innovative...*
teaching methods, resource requirements, research profile and research management, occupational health and safety issues and collaborative links between the sectors. (p.xviii)

Five years later, it was abundantly apparent that this crucial recommendation had not been enacted and certainly not unilaterally across all (32) university chemistry departments. This inactivity was critical support for the proposed project.

Another recommendation similarly had not been achieved in 1998:

*The RACI Course Accreditation Committee should publish a report on a triennial basis detailing the merits and shortcomings of chemistry courses in Australian universities having regard to international standards.* (p.xviii)

Hence, in 1998, there were no data available on the quality of Australian university chemistry courses – particularly on the Chemistry 1 course and equally important, there were no data available on the quality of the Chemistry 1 course in relation to similar international courses. Such a critical need provided further impetus for the proposed project.

Another critical recommendation had not been enacted in 1998:

*The RACI Chemical Education Division should provide resource materials for the design and content of undergraduate courses through the establishment of chemical education course advisory centre.* (p.xviii)

The fact that such an advisory centre had not been established 5 years after the review recommendation suggested the ineffectiveness of the RACI in ‘influencing’ chemical education in the Australian university sector.

Another recommendation related to the importance of laboratory exercises:

*University authorities should recognize that practical experience in chemistry is of vital importance to the discipline.* (p.xix)

It was most obvious that in 1998, chemistry departments were struggling to maintain the minimum required hours of practical laboratory work for Chemistry 1 students. This was a consequence of progressively reducing departmental operating budgets and staff shortages – including reduced numbers of technical support staff. This factor had a direct impact on the quality of the Chemistry 1 course and its effectiveness as a foundation science course at the tertiary level.
Another recommendation related to the service course stigma of Chemistry 1:

_University chemistry courses should be taught by academics with recognized qualification in chemistry and an active participation in the discipline. The trend for service chemistry courses to be taught by non-specialists should be resisted._ (p.xx)

At this time, other science departments, particularly biology, were insisting that they teach ‘the chemistry they need’ in Year 1. Naturally, this was vigorously resisted by Chemistry Departments on financial grounds rather than on course quality.

A final recommendation related to HSC/VCE Chemistry:

_School chemistry courses in Years 11 and 12 should be taught by chemistry teachers who have satisfactorily completed at least two years of tertiary chemistry courses._ (p.xxi)

Five years later, there was little evidence of this in schools where it was common for general science teachers to teach senior chemistry. Further, the decline in chemistry enrolments at the tertiary level was ‘blamed’ directly on this factor and as a result, students were not attracted to chemistry and achieved a less than acceptable level of chemical literacy.

There was also one recommendation on the responsibility of chemistry to society:

_The chemistry profession should undertake more coordinated activities to promote the importance of chemistry for Australia’s economic and social advancement._ (p.xxx)

Five years later there was no tangible evidence to suggest that this recommendation had been carried out.

All these recommendations appeared to be appropriate and timely to the overall advancement of the status of chemistry in Australia. The fact that some five years hence there was no obvious evidence to suggest that any of them had been enacted tended to suggest that this default was a serious contributor to the chemistry crisis phenomenon noted in 1998. This was also a firm foundation for the proposed project.

An excellent history and philosophy of the Australian post-secondary chemistry curriculum essay was published by Rae in 1996. He made the critical observation that –
Thus, there had been no attempt to review the Chemistry 1 course nationally or any attempt to set benchmarks for content and there had been no attempt to assess the effectiveness of the traditional course or to restructure the curriculum. From the introduction to Rae’s essay, it was evident that this had not been done for at least three decades! Here then was another critical piece of evidence to suggest that the proposed project was both overdue and an essential element in the ‘chemistry in crisis’ debate. It was Reece (1966) who published the first comprehensive survey of Australian university chemistry courses and for the Chemistry 1 course the norm was three lectures per week, three hours of practical work and an optional tutorial. Three decades later, this was still the norm for the traditional Chemistry 1 course.

Rae made another critical observation that –

\(\text{(n)o formal processes exist by which the curricula are decided in university chemistry departments.} \) \(\text{ (p.238)}\)

and –

\(\text{(u)niversity staff seldom meet formally to plan the curriculum, few departmental reviews have been conducted and there are no mechanisms for regular review and re-accreditation of the curriculum.} \) \(\text{ (p.239)}\)

Hence, it could be concluded that any changes to the Chemistry 1 curriculum were made on a ‘needs basis’ and not via any well-defined and systematic process of review and reform. Thus, the anecdotal evidence in 1998, that reform and restructuring of the Chemistry 1 course was necessary was a gross understatement of the situation and proved to be a critical element of the proposed project.

In terms of the teaching of chemistry at the tertiary level, Rae concluded –

\(\text{(c)ommon sense tells us that no matter what is taught or how it is taught, educational outcomes are determined by student behaviour.} \) \(\text{ (p.251)}\)

and –

\(\text{Australian chemistry teaching at the post-secondary level is sound but not often innovative, reactive rather than making} \)
the pace and lacking a tradition of curriculum development such as exists in secondary education. (p.251)

This observation precisely parallels the anecdotal evidence noted in 1998 that students are ‘switched off’ from chemistry because they believe that the content is dull and obscure and they do not enjoy the subject. This surely is the most compelling evidence for a comprehensive review of the Chemistry 1 course, not only in terms of its content but also in terms of its effectiveness as an essential foundation tertiary science course.

Some quantitative evidence was required to support the observation that student enrolments in chemistry were in decline and that this trend was continuous throughout the 1990’s. A report to the Ministerial Committee of Advice to the Victorian State Minister for Tertiary Education and Training, published in 1997, confirmed this general trend:

The overall demand for university studies in science has increased over the past five years and higher achieving students are choosing science to an increasing extent. Despite this overall increase, there has been a significant reduction in demand for the physical sciences and for general undergraduate science programs. In comparison with other countries, Australian participation in studies in physical sciences and engineering is low and the proportion of students progressing to postgraduate studies in science and engineering is also relatively low. (p.3)

The report also addresses the shortfall of students studying science at the secondary level:

The number and proportion of students in sciences at senior secondary levels is declining. (p.4)

And on career prospects for science graduates:

Graduate employment surveys show significant numbers of graduates still seeking employment six months after completing programs. Employers of science graduates have argued strongly for a clear science and technology policy to guide both economic development and responses from the education system. (p.4)
In addition to quantifying the decline of student participation rates in secondary and tertiary science courses, this report highlights a number of related factors that all appear to contribute directly to the ‘demise of chemistry’ in Australia, as was noted at the end of the 20th century. It was apparent that all these factors needed to be further investigated in the proposed project.

The report on ‘Demand for Tertiary Studies in Science and Technology’, published in 1997 called for ‘a clear science and technology policy’ in the 21st century and such a policy was proposed by the Federation of Australian Scientific and Technological Societies (FASTS) in 1998. Numerous recommendations were included, most notably:

*Australia needs a cultural change in the social perception of science, technology and engineering. Promoting community debate on science and technology is essential if we are to make important decisions on improving our wealth and quality of life. Government is in a unique position through its broad range of portfolios to inform the general public on the importance of science and technology to business, employment, the community and the environment.* (p.9)

The following three policy statements are critical to the ‘chemistry in crisis’ debate:

*Due recognition should be made of the important roles that science and scientists play in wealth creation, employment and improved environment and lifestyle in modern society.*

*FASTS believes that scientists should contribute to public debate on scientific issues.*

*Communication skills should be seen as an essential part of the education and professional development of scientists.* (p.10)

It is intuitively obvious that all these skills have to be regarded as essential educational outcomes of the Chemistry 1 course if it is to be regarded as producing an acceptable level of chemical literacy to equip students to relate chemistry to the society of which they are a part.

Reference is also made to the ‘science for all’ philosophy in science education:
All people should have an understanding of scientific principles and methods and an awareness of scientific and technological applications to everyday life. This should be a cultural goal and is integral to fundamental literacy in a modern society. It enables people to make informed judgments about the benefits of science and technology to society. It will only be achieved by a national commitment to excellence in science and mathematics education for Australians at all levels, primary, secondary and tertiary. (p11)

Mathematics is mentioned as a critical component of scientific literacy. Anecdotal comments from chemistry academics indicated that the mathematics skills of Chemistry 1 students were very limited and this was another reason for their inability to succeed in chemistry. Further:

FASTS believes Australian science and mathematics education is at the crossroads. Access to quality teaching and resources is becoming more restricted at a time when all young Australians should be encouraged to pursue high levels of scientific and mathematical literacy. This issue must be addressed if Australia is to have a place in a global economy built on technology and innovation. (p.11)

In 1998, it was apparent that the ‘access’ was available but the ‘motivation’ was lacking. FASTS continues:

Australia needs an increased supply of highly trained graduates, researchers and teachers in science and mathematics. Declining numbers of students in faculties of science, engineering and education across the tertiary sector should be viewed with alarm. (p.13)

This becomes a major policy statement:

An adequate supply of graduates and postgraduates in science and mathematics is essential for the national economic, social and cultural well-being. (p.13)

Finally, FASTS makes the critical observation for the need to increase research in science and mathematics education:

Mathematics and science education must be underpinned by research into areas such as the use of technology in teaching, the study of appropriate curricula for a technological society
and the extent of student participation in mathematics and society. Mathematics and science education should be priority areas in the national educational research agenda. (p.14)

Here was the ultimate rationale statement for the proposed project.

It is always encouraging if further endorsement of a research project is forthcoming after the project has commenced. It was essential to test the severity of the chemistry crisis as perceived not only by the chemistry community but also by the community at large. Therefore in 2001, the author submitted a letter to ‘The Age’ newspaper titled ‘Australian Chemistry in Crisis’ (Appendix 1). This detailed the various factors which were believed to be contributing to the crisis scenario and it was hoped that it would attract an appropriate level of concern within the wider community. The written response was zero and the verbal response from the chemistry community was largely negative – arguing that the situation had been exaggerated. This in reality indicated the acute level of conservatism within the chemistry academic community which had prevailed for decades and certainly prevailed at the turn of the 21st century. Here was a critical factor in the equation – a resistance to change the present chemistry profile which for the present project translated to a resistance by the academic chemistry community to change the traditional Chemistry 1 course. This factor added additional challenge to the proposed project and confirmed its essentiality. It was also an ‘alarm call to action’ to the chemistry community which went poignantly unheeded.

However, in 2001, the RACI published a media release on the theme ‘Rebuilding the Enabling Sciences – Reclaiming the Nation’s potential’. This was a joint statement by the professional institutes of physics, chemistry, mathematics and engineering. Essentially, the statement defined the ‘chemistry crisis’ thus:

If the current rate of university science staff losses continues, there will be no chemistry, physics, mathematics and engineering departments to support innovation and technological advances beyond 2020 and if the rate of secondary school participation in the enabling sciences continues, these sciences will disappear from the school curriculum by 2020.

Statistical data to support this primary claim was provided by an analysis of a survey conducted by Evans (2001) on the ‘health’ of chemistry departments in Australian universities. Both the original statement and the Evans report are included in
Appendix 1. A very clear statistic was that whereas the total number of students being taught chemistry in Australian universities had remained substantially constant during the 1990’s, the total number of staff – both academic and support staff – had declined substantially over the same time frame in the majority of chemistry departments. Thus, student/staff ratios had climbed alarmingly. The Evans report indicated a plethora of disturbing issues – declining chemistry department operating budgets, decrease in the depth and breadth of university chemistry courses especially with respect to laboratory sessions and tutorial support, leading to an overall quality decrease in chemistry courses. It also revealed a lower research output of chemistry staff because of higher teaching loads which coupled with less success with research grant applications leads inexorably to fewer postgraduate students and a declining research profile for the department. In short, the Evans report found that the chemical education system in Australia is in crisis because chemistry in our universities is progressively becoming ‘self-eliminating’. The ‘self-eliminating’ factor however, seemed to be treated by the chemistry academic community with a measure of complacency and this was an anachronism that was especially worthy of investigation in the present project. The author (Hill, 2002) praised the RACI ‘enabling sciences’ initiative (Appendix 1) but urged the establishment of an action campaign to address the key problem identified and indicated that his research project was focused on a review and restructure of the Chemistry 1 course which was believed to be a critical element in addressing at least in small part the overall problem of the demise of Chemistry in Australia.

Further support for the present project was forthcoming from a study commissioned in 2003 by the Australian Council of Deans of Science titled ‘Science at the Crossroads’ and was a study of trends in university science from ‘Dawkins’ to now – 1989 to 2002. Most importantly, it gave accurate participation rates in tertiary chemistry over the decade 1992 to 2002. The report suggested that –

\( (d) \text{declining Year 12 enrolments are one of the explanations of declining university science enrolments.} \) 

(p.2)

Over the period of the survey, the highest Year 12 science enrolments were in biology which showed a decline of some 3% from 1992 to 2002. The second highest enrolment was in chemistry which also showed a decline of some 2% over the same period. Psychology enrolments however increased by 5% over this period. The report suggests:
So far as science is concerned, these statistics suggest a decline in senior school science which must go at least part of the way to explaining the decline in the fortunes of university science. In the case of mathematics, there has been an increase in Year 12 enrolments. However, it is possible that such growth has come about by students enrolling in terminal mathematics subjects, successful completion of which would not prepare them for university mathematics. (p.81)

Anecdotal evidence clearly pointed to an inadequacy of mathematics skills inherent with Chemistry 1 students and this was certainly a limiting factor in their ability to cope with the course and to excel in it.

The summary statement of the report effectively quantified the ‘chemistry crisis’ and uniquely endorsed the need for the present project:

‘Science at the Crossroads’, one regrets to say, shows that the previously noted decline in science between 1989 and 1997 has continued into the new century. The downward trend in the teaching of many areas of traditional science has now been with us for over a decade. 1993 was the zenith for chemistry. (p.83)

Here was clear evidence that the demise in chemistry in Australia was a multi-faceted phenomenon and that chemical education at all levels was at the centre of the overall problem. Therefore the proposed project had to focus not only on reform and restructure of the Chemistry 1 course but it also had to address the overall ineffectiveness of chemical education in Australia at both the secondary and tertiary levels. The dimensions of project were thus inevitably increasing as it progressed.

A more recent initiative which further endorsed the value of the present project was the ‘Future of Chemistry’ project undertaken by the RACI in 2004. The author is a member of the Steering Committee of this project which was probably initiated by a statement by the Queensland Chief Scientist – Professor Peter Andrews as published in the ‘Sydney Morning Herald’ in August 2004. The statement commented on the ‘shortage’ of professional scientists particularly those skilled in the enabling sciences to support the existing and emerging industry sectors of the Australian economy:
Australia needs an additional 75,000 scientists by 2010 if it is to meet the demands of a knowledge economy. 25% of science-based academics are likely to leave the profession within the next 5 years. The number of chemistry PhD’s has fallen from around 18 per million Australians in 1969 to 8 per million population in 2003.

In order to quantify this statement more precisely in terms of trained chemists, the RACI initiated the ‘Future of Chemistry’ project in 2004 to examine the supply/demand nexus of chemistry graduates in Australia. The essential conclusions of this project are summarised in Chapter 9.

The rationale for the proposed project is fundamentally based on the premise that if chemistry is to successfully project itself as the true ‘enabling science’, it must shed the inherent educational boundaries which have been impeding its advance for so long. Chemistry must ‘reinvent itself’ if it is to maintain its dominance as the enabling science of the 21st century. With its focus on reform of the tertiary Chemistry 1 course, it is believed that this project can, at least in a modest way, make a contribution to these essential re-invention and re-vitalisation processes.

1.2 RESEARCH QUESTIONS

The fundamental aim of the proposed project is to develop a curriculum framework for the reform of the Chemistry 1 course in undergraduate study in universities. Such a development will be informed by the results obtained from consideration of the following research questions, each of which is considered as a major research initiative within the proposed project framework.

**Question 1** (The major research question)

*How can the curriculum used in Chemistry 1 in Australian universities be reformed to arrest the decline in interest in this enabling science?*

Anecdotal evidence suggests that there is no ‘common’ curriculum for the tertiary Chemistry 1 course in Australian universities which has been benchmarked and directly aligned with comparable international courses. Further, there is evidence (Rae, 1996) that there has been no comprehensive review of tertiary chemistry curricula in Australia for at least the last three decades. It is apparent that the changes
that have occurred to the tertiary Chemistry 1 curriculum over the last decade have been minor and insufficient to directly reverse the trend of declining selection of chemistry as a major by prospective tertiary science students.

Question 2

Why is the Chemistry 1 course in Australian Universities failing to attract students and, in particular, students who want to study chemistry as their major?

The declining demand for chemistry at the tertiary level has been apparent for at least the last decade and it is clear that Heads of Chemistry Departments in Australian universities are very concerned about this trend. In terms of the present project, it is necessary to find out the extent of these concerns and the associated concerns with respect to the present Chemistry 1 course curriculum.

Question 3

What are the factors promoting change to the (traditional) Chemistry 1 course curriculum?

It is apparent that the declining demand for chemistry courses at the tertiary level is not the only imperative driving change to the Chemistry 1 course curriculum. It is necessary therefore to find out the wider range of imperatives which are impacting on such a curriculum change.

Question 4

What is the status of Chemical Education in Australia and how is this affecting the decline of chemistry nationally and in particular, the declining student interest in chemistry?

A superficial survey of the chemical education literature has revealed that chemical education research in Australian universities is very limited in scope and intensity. It is necessary to find out why this is so and whether there is a direct correlation between this limitation and the overall demise of the status of chemistry in Australia.
Question 5

What is the status of Chemical Education internationally, particularly in the USA, UK and Europe and is the demise of chemistry in these regions consistent with that in Australia?

A provisional survey of the international chemical education literature has revealed that a decline in the status of chemistry has been experienced in these regions over the last decade but strategies have been developed to address this trend. It is necessary to find out which of these strategies have been successful and, in particular, how the decline in demand for tertiary chemistry courses has been addressed.

Question 6

What are the constraints impeding change to the Chemistry 1 course curriculum?

Anecdotal evidence from discussions with the Australian academic chemistry community shows that university chemistry departments are continuously being subjected to numerous constraints in addressing essential changes to maintain their viability and sustainability as an academic entity within a Faculty of Science structure. It is necessary to find out the nature and range of such constraints and how these impact on changes to the Chemistry 1 course curriculum.

Question 7

How can contemporary educational theories assist in the construction of a new Chemistry 1 curriculum framework?

It is necessary to review contemporary educational theories both generic and chemical and then use these as the foundation structure of a new Chemistry 1 curriculum framework.

Question 8

How can such a curriculum framework best be promoted and what are the likely outcomes of its adoption?

Conservatism and a reluctance to accept change are well-known characteristics of the Australian chemistry academic community, as evidenced by no significant changes to the Chemistry 1 course curriculum being enacted over the last three decades. Inevitably, any major change to the existing (traditional) Chemistry 1 curriculum will
be difficult to promote and effect adoption. It is necessary to explore strategies by which these essential objectives can be achieved.

1.3 RESEARCH METHODOLOGY

The major research question is addressed by reference to a detailed analysis of a number of generated data fields which relate directly to Questions 2 to 7 inclusive. Questions 2, 3, and 6 are addressed by undertaking a qualitative semi-structured interview program with Heads of Chemistry Departments in selected Australian universities, seeking their views on the status of the present Chemistry 1 course and the changes that they believe are necessary within the existing constraint environment. Question 4 is addressed by a compressive review of the developments in Australian chemical education over the last decade and similarly, Question 5 is addressed by a comprehensive review of international chemical education developments, with particular reference to chemical educational strategies which have been employed to address the declining interest in chemistry at both the secondary and tertiary level. Question 7 constitutes the ‘theoretical statement’ of the present research and Question 8 is addressed in terms of the projected outcomes of the project.

1.4 SCOPE AND LIMITATIONS

The scope of the project, as inferred from the eight research questions given in Section 1.3, is potentially vast and therefore the proposed project has to have limitations imposed on it. Question 4 implies a comprehensive review of chemical education in Australia at the secondary and tertiary levels and Question 5 implies a similar review of chemical education internationally. These are major stand-alone individual projects by any criteria of assessment but such research is essential to provide a comprehensive overview of the present status of chemical education globally and the extent to which Australia is in tune with major chemical education developments, particularly at the tertiary level. It is intended to address Questions 2, 3 and 6 by undertaking a comprehensive review of the Chemistry 1 course in Australian universities. Herein lies the initial limitation on the project since it is assumed at the outset that the Chemistry 1 course is an exemplar of the status and effectiveness of tertiary chemical education in Australia from the perspective of
believing that this course is critical for providing a foundation of chemical literacy for the scientific community.

The second limitation is that the review of the Chemistry 1 course will be undertaken via a semi-structured interview program with Heads of Chemistry Departments in selected Australian universities. Although it is intended to include as many chemistry departments as possible in the program, limited research funding for the project overall means that probably not more than two-thirds of the Australian university chemistry departments will be included in the survey. It is the intention to include chemistry departments in all States and Territories and to include both the ‘traditional’ (red-brick) universities and the newer universities in the program. It is also intended to include ‘stand-alone’ chemistry departments and those which are amalgamated with other science departments.

A final limitation is that the overall scope of the proposed project with the imposed limitations is probably insufficient to provide all the answers to the critical question ‘Why is Australian Chemistry in crisis?’ but sufficient indicators should be revealed such that some positive remedial action can be recommended and it is believed that this involves a major change of attitude towards both the philosophy and practice of chemical education in Australia.

1.5 THESIS STRUCTURE

The central theme of the proposed research project is an investigation of the scope and intensity of the perceived ‘chemistry crisis’ in Australia and the multiplicity of factors which contribute to it. In particular, the aim of the project is to define the extent to which this crisis is reflected by declining enrolments in tertiary science – especially in terms of the quality and quantity of chemistry enrolments and an overall reluctance by the chemistry academic community to design a new curriculum for the Chemistry 1 course which reflects contemporary educational theory and practice.

Since the ultimate aim of the proposed project is to propose a new curriculum framework for the Chemistry 1 course in Australian universities, as defined by Research Question 1, Chapter 2 reports the outcomes of an extensive interview program with Heads of Chemistry Departments in selected universities across Australia and gives their views on the present status of the Chemistry 1 course. The important outcomes of these interviews are summarized especially those relating for
the need for changes in the course, changes already made and implementation of contemporary teaching and learning methodologies. Chapter 2 provides the essential answers to Research Questions 2, 3 and, in part, Question 6.

The essential research necessary to answer Research Questions 4 and 5 is discussed in detail in Chapters 3 and 4. Chapter 3 deals is a comprehensive review of the status of chemical education in Australia over the last 10 to 15 years with special emphasis on secondary and tertiary chemistry curricula and their progressive development and interaction, the effectiveness of these curricula in terms of achieving chemical literacy and emphasizing the social responsibility. Also, and equally important is an assessment of the extent to which contemporary teaching and learning pedagogies have been accepted into the Australian chemical education culture. Chapter 4 is a comprehensive review of chemical education developments internationally over the same period with special focus on the extent to which a ‘chemical crisis’ is or has been evident in the USA, UK, Europe and SE Asia and the remedial actions which are or have been taken to remedy this. Chapters 3 and 4 essentially provide a wide range of drivers or imperatives for change with respect to both attitude and philosophy of Australian chemical education, particularly at the tertiary level.

Chapter 5 is a discussion of the ‘constraints’ impeding development of Australian chemical education and particularly, curriculum changes to the Chemistry 1 course. Many of these constraints were highlighted in the interviews with Heads of Chemistry Departments, as detailed in Chapter 2 and many others derived from a review of Australian chemical education discussed in Chapter 3. Many of these constraints are able to be overcome in the short term and these are discussed in terms of their immediate impact on the Chemistry 1 course and the extent to which a proposed curriculum change is impeded. Chapter 5 essentially answers Research Question 6.

Chapter 6 proposes in skeletal form a new curriculum framework for the Chemistry 1 course based on the research reported in the previous four chapters. It is radical in both structure, content, teaching and learning methodologies and vision. In order to test the likelihood of such a curriculum framework being accepted either partially or completely by the professional chemistry community – the proposed curriculum framework was published in ‘Chemistry in Australia’ – the monthly journal of the Royal Australian Chemical Institute (RACI) which has a circulation of
some 6000 covering some 70% of the professional chemistry community. Responses via the journal or to the author were solicited and these were taken into account in refining the framework. These also were a measure of the extent to which the hitherto conservative chemistry community was amenable to change from the traditional to the contemporary in terms of the Chemistry 1 course and thus, in part, provides some insight into answers to Research Question 8.

Chapter 7 proposes a new curriculum framework for the Australian Chemistry 1 course based on a number of fundamental principles and the synthesis of a new educational theory for ‘chemistry’, a contemporary (generic) educational theory and a ‘social responsibility of chemistry’ philosophy. Chapter 7 is the authors’ answer to Research Question 1. Chapter 8 selects ‘chemical thermodynamics’ as an exemplar of the proposed curriculum framework. It is essentially a test of whether the proposed curriculum framework is viable, flexible and appropriate for a 21st century foundation (tertiary) chemistry course which meets the needs and aspirations of a diverse range of students with a diverse range of learning abilities.

Chapter 9 concludes with an overview of the achievements of the project and an evaluation of the principal thesis proposals together with a consideration of further steps which need to be taken if these proposals are to be successfully implemented both in the short and long terms. Chapter 9 is the answer to Research Question 8.

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CHAPTER 2

HEADS OF CHEMISTRY DEPARTMENTS VIEWS
ON CHEMISTRY 1 COURSES

2.1 INTRODUCTION

2.1.1 Rationale for qualitative interview study

When this project began in 1998, there was considerable anecdotal evidence to
suggest that the tertiary Chemistry 1 course needed major reform but there was no
consensus view among the academic chemistry community as to how this should be
done or the scale of the restructure. Since the reform of the curriculum of the
Chemistry 1 course was targeted as one of the major objectives of this project it was
necessary to canvass the views of the present course from the perspective of Heads of
Chemistry Departments. The aim was to use the collective wisdom and concerns of
Heads of Chemistry Departments to confirm or otherwise the anecdotal evidence on
the need for reform of the Chemistry 1 course which had derived from discussions
with the chemistry academic community and also to understand the present state of
chemical education in Australian universities.

2.1.2 Scope

University Chemistry Departments around Australia (all States and Territories
except Tasmania) were visited by the author. The initial aim was to achieve a
‘national’ viewpoint on the status of the Chemistry 1 course. Two days were spent at
each stop-over and five hours at each selected chemistry department. Interviews with
each Head of Department lasted a minimum of one hour and a maximum of one and a
half hours. The following universities were included in the program: Australian
National University, University of Canberra, ADFA(University of NSW), University
of Adelaide, Flinders University, University of South Australia, University of
Western Australia, Murdoch University, Curtin University of Technology, Edith
Cowan University, Charles Darwin University, James Cook University, University of
Queensland, Queensland University of Technology, Griffith University, University of
Newcastle, University of NSW, McQuarie University and the University of
Wollongong. This wide range of universities was selected on the basis of obtaining a
balanced perspective on the Chemistry 1 course from the ‘traditional’, ‘applied’ and
‘new-age’ type of chemistry department - the latter type usually being one component of a broader-based science department within a Faculty of Science. It was also essential to gauge the scope and depth of the anecdotal concerns with respect to the Chemistry 1 course in terms of a ‘localized’ (State) problem or a delocalized (National) problem. It was not possible within the scope of this research to visit all thirty-two chemistry departments (due to time and funding constraints). It was decided not to include university chemistry departments in Victoria and Tasmania, since if insufficient data were forthcoming, these could be visited later in the project. Although major chemistry departments were thus eliminated from the study such as Melbourne, Monash and Tasmania, a sufficient number of these were included in the study. In addition, the author was well aware of the views of La Trobe chemistry academics on the Chemistry 1 course. Thus, on balance, it was believed that the scope of the proposed interview program was sufficient to meet the objectives of the research questions.

2.1.3 Limitations

La Trobe University ethics approval for the interview project stipulated that only ‘institutions’ be quoted and not interviewees, hence those interviewed are not identified by name. [Note: At this time, the author was enrolled as a PhD candidate at La Trobe University, but transferred his candidature to the University of Melbourne in 2000, subsequent to the relocation of his supervisor.] Time constraints precluded additional interviews with Chemistry 1 Coordinators, Chemistry 1 lecturers and Chemistry 1 students. Such additional contributions to the data base would have been valuable in terms of revealing the interface between the ‘teaching and learning’ elements of ‘Chemistry 1’. In this context, it is recognized that the data obtained from the Head of Department interviews, whilst obtained in good faith, may not reflect their true perceptions of the status of the Chemistry 1 course in their department, since it is only natural that each Head of Department presents the ‘best possible image’ of the course, whilst being prepared to acknowledge only limited shortcomings. A further potential limitation on this project is that ‘scientists’ are generally reluctant to ‘talk’ with ‘educationalists’. The divide between the sciences and the humanities was articulated as long ago as 1956 by C.P. Snow in his famous lecture entitled ‘The Two Cultures’ (Snow, 1956) and also by Brown et al. (1989). However, in the case of this research, the author was perceived by the Heads of Departments as having credibility as an academic chemist and it was well known nationally that he has been teaching
Chemistry 1 for more than 30 (continuous) years. This fact eased the potential difficulties that can arise in dealing with senior scientists whose research is in the quantitative paradigm.

It was somewhat unfortunate that with one exception, the Heads of Department interviewed did not currently teach Chemistry 1 but implicitly believed that the ‘best teachers’ in the department should be involved in the delivery thereof – thus recognizing the pivotal significance of this course in a science degree. However, they were obviously in a position to initiate and effect changes in the curriculum and pedagogy subsequent to appropriate discussion with the lecturers involved. The interviews were also designed to assess the attitude of Heads of Department towards practical (laboratory) exercises and to ‘flexible teaching methodologies’ in terms of revealing limitations with these aspects of the Chemistry 1 course.

2.2 THE RESEARCH METHODOLOGY

The research program was essentially in two parts – an interview with the Head of the chemistry department at which answers were solicited to a (pre-prepared) set of sixteen questions and a related questionnaire consisting of twenty questions which could be returned subsequent to the interview. The questionnaire focused on factual information relating to the structural profile of the department and the structure of the Chemistry 1 program and its function. Also, questions were included on recent structural changes that have been made to the course and the teaching methodologies used. In contrast, the interviews were designed to elicit as much information as possible within the set time-frame on the current situation with respect to the status of the Chemistry 1 course, to elicit views on the ‘difficulties’ and ‘constraints’ facing the department and, in particular, to discern any ‘reforms’ to the course which have recently been initiated. The questionnaire and the interview question set were thus complimentary and taken together, were designed to deliver a rich data base capable of cross-referencing, not only on the status of the Chemistry 1 course (in 1999) but also the status of chemical education in Australian universities.

In order to elicit comparable data from the discourse, a semi-structured interview style was used based on the ‘interview guide approach’ (Patton, 1990) using a qualitative purposeful sampling technique. Within each of the interviews, it was possible to ‘explore, probe and ask additional questions’ to ‘elucidate and illuminate’
the subject matter of each question. All interviewees were asked the same set of sixteen questions and depending on the detail of the responses, the interviews varied in length but none were shorter than one hour. Prior to each interview, a ‘relaxed atmosphere’ was established with each interviewee such that the interview would be of maximum inherent value. This was achieved by holding informal discussions with the interviewee ‘off the record’ prior to the recorded interview on the structure of the Department and its historical development. Frequently, this was supplemented by a Departmental tour. This approach is consistent with the recommendations of Fontana and Frey (2000) who have emphasized the importance of developing a rapport with the interviewee as an essential element to building confidence and trust. The preliminaries usually included a tour of the department and an informal meeting with staff. The interviews were taped and representative citations quoted thereafter are faithful transcriptions from the taped interviews in accordance with the procedures of Ryan and Bernard (2000). To adhere to the relevant ethics permit for this project, citations are referenced to the institution rather than to the interviewee.

2.3 THE INTERVIEW QUESTIONS AND ASSOCIATED QUESTIONNAIRE

The interview question set was designed with the view of obtaining quantitative data on a range of issues and qualitative data relating to known anecdotal concerns about the structure and status of the Chemistry 1 course. The question set was designed to gauge the issues confronting the departments and the extent to which chemistry departments nationally are addressing them. Thus, the interview questions ranged over ‘course structure’, ‘student intake demographics’, ‘course constraints’, ‘teaching strategies’, ‘curriculum’, ‘student response’, ‘pre-requisites’, ‘significance of an education qualification for Chemistry 1 lecturers’, ‘perceived change drivers in Chemistry 1’, ‘enforced developments of the course’, ‘role of the professional chemistry society’, ‘future of chemistry as a core academic (science) discipline’, ‘the influences of the global chemical education debate’, ‘strategies to enhance students’ appreciation of chemistry’ and ‘attitudes towards reform of the course’. In addition, each participating Head of Department was sent a brief questionnaire on the structure of their department and on the structure of their Chemistry 1 course. [The questionnaire, the interview question set and a list of supplementary materials
supplied by the chemistry departments visited are given in Appendix 2.] The interview question set is reproduced below. A brief rationale for each question is included here and the questions were designed to probe a wide range of issues within a pre-defined time-frame:

**Q1** Briefly, what is the structure of your Chemistry 1 program and what has been the demographic impact of other science courses (particularly biological science courses) on your Chemistry 1 intake over the last five years?

The associated Questionnaire, sent to participating Heads of Departments prior to the interviews, was designed to give a detailed structure of each Chemistry 1 course but since, it was unlikely that all of these would be returned, it was appropriate to ask for a brief summary structure of the course in the interviews since it was important to understand the scope of the course and the associated difficulties before the restructuring process could begin. It was known prior to this interview program that most chemistry departments offered (at least) two Chemistry 1 courses, one for students who had previously studied chemistry and another, usually titled ‘Basic Chemistry’, for those who had not. It was important to find out whether the Chemistry 1 course structure was essentially similar across the nation at least in terms of the topics included and whether the outcomes (standards) of these courses were similar. Further, it was important to find out the emphasis placed on laboratory exercises as a key part of the Chemistry 1 course, since it was known that over the decade of the 1990’s, laboratory exercises in Chemistry 1 had progressively declined in number due to various constraints imposed upon chemistry departments. [These ‘constraints’ form the basis of Chapter 5.] It was also important to find out how each Chemistry 1 course addressed the issue of a ‘suitable reference text’ – since it was known that there were a range of concerns on this issue. Whilst there is a very wide range of texts available to support ‘Chemistry 1’, the most commonly used texts are of American origin and do not relate to ‘Australian Chemistry’ sufficiently well to directly attract our students to chemistry. Further, most Australian Chemistry 1 courses contain a significant proportion of organic chemistry (largely to satisfy the requirements of the biological sciences) and the American ‘Chemistry 1’ texts are usually deficient in this domain. Thus, it was important to find out the emphasis placed on organic chemistry in each Chemistry 1 course and how was the issue of a suitable reference text addressed.

The other focus of Q1 was the ‘health’ of the Chemistry 1 course. It was already known that commencing (science) students generally had a negative image of
chemistry for a variety of reasons and hence only studied Year 1 chemistry as an enforced pre-requisite for another science major – particularly a biological science major. Some student views on the Chemistry 1 course are discussed in Chapter 3. It was known that ‘Chemistry 1’ is not a major influence on changing this perception, as evidenced by difficulty in retaining students in chemistry beyond Year 1. In a climate of decreasing government funding for universities and increased competitiveness between universities coupled with the progressive introduction of science courses that appear to provide students with well-defined career paths, university chemistry departments are being progressively relegated to merely providing ‘service courses’ for these seemingly more attractive courses. This issue is discussed further in Chapter 3. It is important in this study to quantify this trend and to find out how chemistry departments are reacting to this apparently irreversible trend even though it is recognized that popularity indices of science courses have a cyclical dimension.

Q2 What are your major concerns for your department and how do these concerns impact on your Chemistry 1 course (program) and how are these concerns being addressed?

Australian universities have been involved in at least a decade of major infrastructural changes that have radically altered their profile and, for many, their mission. At the same time, the student population has changed irrevocably in character, partly as a result of changes to the secondary school curriculum and perhaps more importantly, because modern students are much more sensitive to the ‘education for employment’ syndrome. The introduction of a ‘user-pays’ system into post-secondary education has exacerbated this attitude. Further, it was known at the time of these interviews that all chemistry departments had suffered at least a decade of financial constraints which had severely impacted on staffing – both academic and non-academic and on infrastructure – particularly laboratory and information technology infrastructure. This major constraint had impacted severely on all courses, an particularly on Chemistry 1 in view of the ‘labour – intensive’ nature of this course and the proportionally large number of students involved. It was thus very important to find out how chemistry departments have managed this on-going situation and maintained a Chemistry 1 course of integrity. All these issues are discussed at length in Chapter 5.
Q3 What teaching strategies are being applied in your Chemistry 1 course and how does student reaction to the course affect those who teach it and how is this expressed?

At the commencement of this project in 1998, it was known that many Chemistry 1 courses across the nation were still delivered by the old traditional ‘chalk and talk’ method although (usually) students were provided with summary lecture notes. Delivery by slides and over-head projection was also common, again with supplementary notes provided. Power-Point projection of lectures was just coming into prominence. Student dominated Quality Assurance schemes adopted by most universities in the ‘90’s was the principal driver for instigation of new teaching methodologies but at that time, chemistry departments, for a range of reasons, were somewhat reluctant to adopt these. These issues are discussed at length in Chapter 3. Hence, it was important to investigate the extent to which new teaching strategies in Chemistry 1 had been adopted, not only in terms of hardware but also in terms of educational philosophy and the extent to which student reaction has predicated and supported this.

Q4 What chemical concepts and ideas do you regard as conceptually difficult and challenging at the Chemistry 1 level and to what extent is the demand that you place on manipulative skills and learning of new techniques a determinant of achievement in the course? To what extent is ability in mathematics a determinant of achievement in chemistry and, in your opinion, is there a defined core of knowledge and an essential set of experimental skills inherent in your Chemistry 1 course? How do you justify your choice of ‘knowledge core’ and ‘experimental skill set’?

It was well-known that the issue of what constitutes a ‘core of chemical knowledge’ in chemistry is a perpetual debate of considerable intensity even though most basic chemistry texts follow a common sequence of ‘core’ topics. Most prominent in this debate has been the Chemistry 1 teaching staff at Flinders University who published a very useful introductory chemistry text in 2000 (Martin & Zeegers, 2000). It was also known that Chemistry 1 courses differed somewhat in the range of core topics included and in intensity of coverage. The latter appeared to be pre-determined by the degree of difficulty with these topics which successive cohorts of students experienced. Invariably, it was physical chemistry topics or topics associated with mathematical manipulations which received the least amount of coverage. Thus, it was important in the interviews to explore the connected issues of
What measure(s) do you have of students’ enjoyment of the Chemistry 1 course and how do you measure this?

It is self-evident that the future health and viability of Chemistry 1 is dependent on student acceptance and enjoyment of the course but at the commencement of this project in 1998, there was little if any data available on this important parameter. The usual ‘acceptance/enjoyment’ data are found in (annual) Quality Assurance questionnaires as returned by participating students but these are rarely sufficiently detailed or comprehensive. Individual Chemistry 1 course coordinators may use additional measurement factors such as lecture, tutorial and laboratory attendance rates and examination pass rates which, albeit indirectly, relate to this issue but which are not widely published. Student enjoyment and satisfaction of Chemistry 1 has a direct impact on chemistry retention rates and an additional aim of this project was an attempt, through the present interviews, to quantify this trend.

Is Year 12 ‘Chemistry’ a necessary and sufficient pre-requisite for your Chemistry 1 course?

Throughout the 1990’s, the universities made a deliberate effort to increase enrolments and Faculties of Science were particularly vigorous in this respect. This recruitment drive in the sciences was largely made possible by two initiatives: the abolition of ‘pre-requisites’, particularly in the enabling sciences and the introduction of a wide range of what came to be called ‘niche’ (science) degrees, specifically introduced to meet professional employment opportunities in these domains. Thus, students were enrolled in chemistry who not only did not have a pass in a senior high school chemistry course but also may not have studied chemistry previously. This enforced (at least) a bisection of the traditional Chemistry 1 course into ‘Chemistry 1 for chemistry majors’ and ‘Basic Chemistry’ – the latter essentially being a ‘service course’ for those Year 1 science courses which stipulated ‘Chemistry 1’ as a core subject. The larger chemistry departments such as the University of Sydney developed a range of ‘Chemistry 1’ courses for specific groups of science students, whilst retaining a more traditional Chemistry 1 course for those commencing students who have selected chemistry as their major. It was expected that those chemistry departments which offered the latter course would strongly argue for Year 12 ‘Chemistry’ as a pre-requisite even though a pass in the NSW HSC Chemistry may
not be an enrolment requirement. It was important to find out the extent to which the Chemistry 1 course is affected by ‘pre-requisite relaxation’ since ‘standards’ are obviously an issue and it is well known that chemistry departments regard RACI accreditation of their courses, particularly the Chemistry 1 course as a vital signal of their quality and integrity.

**Q7** How do you react to the plethora of science degrees currently available in Australian Universities?

In the late 1990’s, this debate was prominent on two fronts. Firstly, the situation was seen by academic chemists as out of control with too many niche science degrees were on offer but secondly, these niche degrees were seen as saviours for chemistry departments in that student numbers in the basic chemistry course (and its variants) were progressively expanding, thereby sustaining the viability of these departments. A further disturbing trend was that some science departments, particularly the biological sciences were arguing that they should teach the necessary chemistry in their Year 1 course thereby depriving chemistry departments of invaluable service course income. Thus, it was important in these interviews to gauge the degree to which chemistry departments view the growth of niche science degrees and the perceived impact on the Chemistry 1 course. In simple terms, it was important to gauge the extent to which the ‘teach to the market’ syndrome has been accepted by chemistry departments and how they are addressing the internal competitive regimes that are threatening their viability and ultimate survival.

**Q8** If your Chemistry 1 lecturers had a formal education qualification, how would you expect this to affect their individual delivery of the Chemistry 1 course?

It has long been recognized that ‘chemical education’ in Australian Universities has not been accorded the prominence it deserves, both in terms of an ‘enabling discipline’ and, more importantly, as a research field of stature. Thus, in the 1990’s it was rare for academic chemists to have an ‘education qualification’ and even rarer for academic chemists to list ‘chemical education’ as their principal research area. Indeed, at this time there are only a very few chemistry academics in this sector. Thus, in these interviews, it was important to assess whether ‘chemical education’ is respected as a legitimate area of research and whether it is perceived to have an impact on the quality, status and (perceived) image of the Chemistry 1 course. The responses to this (critical) question would indicate the degree of difficulty and complexity of the proposed restructuring process. It was also important to find out if
academic promotion is more difficult to achieve for those staff who claim ‘chemical education’ as their principal research interest.

**Q9** What do you believe are the current pressures underlying change in the Chemistry 1 course?

At the time of these interviews, anecdotal evidence emerging from widespread informal discussions with the Victorian chemistry academic community in the course of the author’s academic duties indicated that the ‘demand for change’ in the Chemistry 1 course was associated with 3 drivers: declining numbers of students electing chemistry as a major coupled with student demand for an upgraded delivery style; financial constraints on chemistry departments leading to a streamlining of courses and finally, internal political constraints leading to an identifiable ‘image-lift’ of the course overall. It was important to find out if these drivers for change had been identified and if associated course enhancements had been implemented and to what extent. It was particularly important to gauge whether any imposed changes had been well-received by participating students.

**Q10** As Head of Department, what direct influence do you have on the continuing development of your Chemistry 1 course?

It was expected that Heads of Department would be most keen to implement progressive changes to the Chemistry 1 course within the framework of a range of internal constraints but some would inevitably ‘go beyond the norms’ to achieve positive and favourable outcomes for the image of the course overall. It is these initiatives which were of particular interest in the context of this research.

**Q11** What role should the Royal Australian Chemical Institute (RACI) play in the development of the Chemistry 1 course in Australian Universities?

It was known that in 1999, there was considerable disquiet about the effectiveness of the RACI in supporting and promoting the chemistry profession especially in terms of enhancing the public image and the benefits of chemistry to society and in advocating the necessity of chemistry in political arenas in advancing the ‘knowledge nation’ status of Australia. It was therefore important for these interviews to reveal the current views on RACI support of chemistry in Australia.

**Q12** What are your future plans to enhance your Chemistry 1 course and what is the rationale for these? What are your attitudes towards new learning methodologies and technologies and are these inherent in your Chemistry 1 course?
It was known in 1999 that at least 3 new paradigms of teaching and learning in the Chemistry 1 course were in operation. The first of these was at the University of Adelaide (Crisp, 1999) which involved the design of a new Chemistry 1 course with the defined aims of encouraging critical thinking, enhancing problem-solving ability, gaining an appreciation of scientific methodology, encouraging professionalism, providing a basis for further study in chemistry and providing a career path in chemistry. Essentially, the subject matter is directly related to ‘chemicals’, their molecular structure, properties and reactivity and, most importantly, their significance in benefiting society. This novel style Chemistry 1 course is further discussed in Chapter 3. The second new style course originated from Flinders University. Chemistry staff developed a new style text book for Introductory Level Chemistry entitled: The First Step: Resources for Introductory Chemistry (Martin & Zeegers, 2000). Unlike typical Basic Chemistry texts, it emphasizes problem solving skills for students, especially those who have no (or limited) prior chemistry experience. The opening chapter is also unique in that it addresses the common problems of students entering university, such as ‘how to cope’ and ‘where to seek help’. The text overall is a very simple to use ‘self-paced learning’ program for basic chemistry and this initiative is discussed further in Chapter 3. The third new initiative is the introduction of ‘green chemistry’ principles into the Chemistry 1 course with the aim of projecting ‘chemicals’ as ‘environmentally friendly’. This is an initiative of the Monash University, ‘Centre for Green Chemistry’ and this is perhaps the most promising curriculum inclusion for improving the student and public image of chemistry in the long term. It was important to discover via the interviews if any further significant new teaching and learning initiatives were included in the Chemistry 1 course.

Q13 What predictions do you make with respect to the future of chemistry in Australian Universities and, in particular, how will these affect the future of Chemistry 1?

In 1999, the paramount concern among academic chemists was that ‘chemistry’ was losing its identity as the central science and was not perceived as an enabling science in the scientific professional community. As a result, academic chemistry departments were mostly down-sizing and being absorbed into larger departments resulting in less than beneficial combinations with ‘chemistry’ being the minor player with consequential minor influence in the larger entity. An example is the chemistry department of La Trobe University which reduced in staff compliment
by two-thirds over the decade 1985 – 1995 and became part of the School of Molecular Sciences along with Genetics and Biochemistry. Likewise, Chemistry 1 was no longer perceived as a prestige science course in Faculties of Science but merely a ‘useful’ basic course for science students. The Chemistry 1 course image is seen to have degenerated to that of a typical ‘service course’ with the student tag of ‘nasty but necessary’.

Q14 To what extent do your future plans (for your Department and for Chemistry 1 in particular) include participation in the world-wide chemical education debate?

It was apparent in 1999 that few Chemistry 1 lecturers in Australian Universities had a formal ‘education’ qualification and that most chemistry departments naively believed that such a qualification would have little influence on the teaching proficiency of this key course. Equally alarming is that chemical education research in Australian Universities had a very low profile in 1999 and there was a national paucity of interest in the international chemical education debate despite the fact that the same chemistry crisis as was apparent in Australia in 1999 was also apparent in the UK several years earlier and as will be discussed in Chapter 4, radical steps had been taken to address this. It was of critical interest in these interviews to discover if the same paradigm of ignorance with respect to chemical education still prevailed in Australian University chemistry departments.

Q15 What strategies do you have to assist students appreciate the relevance of chemistry in everyday life, the richness and need for chemical research and the place of chemistry in human achievement?

It was known in 1999 that Selinger’s famed book ‘Chemistry in the Market Place’ (Sellinger, 1999) has done much to elevate chemistry to a ‘user – friendly science’ and many Chemistry 1 courses had used this as a ‘recommended (supplementary) text. It was of interest to find out the degree to which Chemistry 1 courses had stimulated interest in chemistry per-se by revealing its powerful message of benefiting society in a plethora of ways as distinct from destroying humanity. Unfortunately there are always reports in the media which sensationalize the destructive power of chemistry in the environment and there are many books such as ‘The Shocking History of Phosphorus: A Biography of the Devil’s Element’ (Emsley, 2000) which do likewise.

Q16 Do you have any additional comments on the issue of the perceived need to restructure the Chemistry 1 course?
It was hoped that all interviewees would recognize the urgent need for restructuring the Chemistry 1 course and would offer some creative/novel ideas as to how this may be achieved both in the short and longer time frames. It was further hoped that the short and long term restructures could be differentiated in terms of priority and projected effectiveness.

2.4 INTERVIEW TRANSCRIPTS AND QUESTIONNAIRE RESPONSES

The full unabridged transcripts of the nineteen interviews conducted are given in Appendix 2 together with some notes on each Chemistry Department visited. Two publications have resulted from the interview transcripts since it was believed that it was important to expeditiously publish the major findings of the overall project and it was indicated to each interviewee that a summary report on all interviews would be produced and that they would receive a copy as a courtesy for their cooperation. A summary report was also a requirement of the research grant which supported this project. The published summary report (Hill and Cross, 2001) is also given in Appendix 2 and an earlier (summary) paper published in the Chemical Education Journal of Japan (Hill and Cross, 2000) is given in Appendix 4.

Only eleven of a possible total of nineteen associated questionnaires were returned. However, much supporting literature was appended in many cases, such as Departmental brochures, course structures, course guides and in some cases, pamphlets promoting chemistry as a profession. In a few cases, sets of course notes and associated laboratory manuals for Chemistry 1 were also included in the return questionnaire package. These materials although incomplete, provided a very useful backdrop and reference portfolio to accompany and consolidate the interview transcripts.

The questions comprising the questionnaire are reproduced below and for each a brief (balanced) summary of the responses is given.

Q1 Briefly, what is your departmental profile in terms of staffing, budget and facilities?

Most respondents indicated a progressive decline in both academic and support staff (particularly technical staff) over the previous decade. The ‘newer’ universities, Griffith, University of Canberra (hereafter referred to as UC) and Edith Cowan University, (hereafter referred to as ECU) do not have a ‘stand-alone’
chemistry department and the chemistry group is incorporated into a larger science discipline, such as Biomedical Sciences (UC), Environmental Sciences (Griffith) or Natural Sciences (ECU). At the Australian National University (hereafter referred to as ANU), the Chemistry Department is separate but closely aligned with the famed Research School of Chemistry.

In terms of the Departmental Operating Budget, all respondents indicated a progressive decline in Operating Budget over the previous decade which has presented numerous difficulties and challenges. Most prominent of these is an inability to replace staff, particularly at the senior level: an inability to replace aging equipment and infrastructure and an inability to keep pace with rapidly advancing IT hardware.

In terms of facilities, most respondents believed that over the years, their department had built up excellent teaching, laboratory and research facilities, commensurate with their teaching and research profile. Curtin University of Technology (hereafter referred to as CUT) and Queensland University of Technology (hereafter referred to as QUT) were particularly well-endowed with state-of-the-art research equipment. However, as a consequence of declining resources, maintenance of quality facilities was a constant challenge for chemistry departments, particularly in terms of providing a balanced upgrade of both teaching and research facilities.

At the same time that this research project was being conducted, an independent assessment of the ‘health’ of Australian university chemistry departments was undertaken (Evans, 2001). Many of the responses to the above question in the questionnaire were remarkably consistent with the Evans review which has been discussed in Chapter 1 is discussed further in section 2.5 and also in Chapter 3.

Q2 What is the structure of your Chemistry 1 program?

Most responding departments have at least two courses in the Chemistry 1 program - a course designed for students intending to major in chemistry and a basic course designed for those who do not. The University of South Australia (hereafter referred to as UofSA) has only one Chemistry 1 course, which is a modified Keller plan consisting of twenty modules and four revision modules. In accordance with Keller principles, there are no formal lectures but highly structured tutorials. Some universities (University of Queensland – hereafter referred to as UQ, Griffith, ANU, Flinders, Newcastle and McQuarie) have multiple ‘Chemistry 1’ courses for
individual groups of science students and these departments have adopted a ‘teach to the market’ philosophy in their Chemistry 1 program.

All respondents are attempting to offer a Chemistry 1 cluster of courses which is best adapted to the ‘needs’ and chemical background of the students. From the questionnaire responses, Chemistry 1 teaching appears to be highly student-focused, using ‘teaching and learning best practice’. In particular, the teaching methodology recognizes the declining (pre-tertiary) chemistry background of students and thereby appears to maximize learning opportunities for all students in the course. It was also recognized that this highly interactive teaching philosophy tends to reduce the Year 1 ‘drop-out rate’ and may even retain students in the main chemistry group.

**Q3** Give the names of staff currently teaching your Chemistry 1 course(s) and their research interests.

Most responding departments indicated that it is a general policy that those who teach Chemistry 1 are research active – thereby implementing the philosophy that the best teaching is informed by research. UC has one staff member totally committed to teaching Chemistry 1 but all other responding departments have multiple staff teaching the program. UC, ECU and UW have Chemistry 1 teachers who list ‘chemical education’ as their primary research interest. In most Chemistry 1 programs, senior staff, but not usually the Head of Department, contribute to the teaching and hence in all departments, the teaching of Chemistry 1 is seen as a priority commitment and there is general acceptance that the teaching of Chemistry 1 requires ‘proven quality teachers’.

**Q4** What is the main purpose of your Chemistry 1 course(s)?

There was much consistency in the responses in terms of teaching students basic chemical concepts, basic experimental skills, principles of safety, recording and interpreting experimental results, using basic mathematics to solve quantitative chemical problems and by the end of the course, to ensure that students have some ability to communicate in the language of chemistry (University of Woolongong – hereafter referred to as UW, Griffith). EC ensures students are aware of the relevance and importance of chemistry in everyday life and UQ believes that via its Chemistry 1 program, it gives students a fundamental chemistry foundation. Others (Macquarie, UC, ANU, CUT, Flinders) ensure a chemistry foundation for students majoring in other sciences, thus ensuring that their Chemistry 1 service courses are of a consistent standard to the major Chemistry 1 course. The aim of QUT is ‘to take students from
diverse chemical backgrounds and bring them to a standard so that they can progress in other sciences or continue as chemistry majors’ and the aim of the UofSA Chemistry 1 course is to ‘empower students in chemistry’. The University of Newcastle (hereafter referred to as UN) states defined outcomes for each topic within the Chemistry 1 course and these are given in advance to students.

Q5 Are science bridging courses offered in your Department?

Some responding departments (UW, ECU, Macquarie, UN, CUT, Griffith) offer a Chemistry Bridging Course. Those which do not believe that the content of a Chemistry Bridging Course is melded into one or more of their Chemistry 1 courses. Others (UQ, UC, ANU) recognize the need and plan to introduce one. Chemistry Bridging Courses are generally conducted during or pre-orientation or as a summer school component. There appears to be general acceptance that the Chemistry 1 course has to make allowances for students with ‘nil chemistry’ backgrounds.

Q6 What changes have you made to your Chemistry 1 course(s) over the last five years and why were these changes made?

All responding departments indicated that ‘change’ in Chemistry 1 is an ongoing process, consistent with ongoing review of the course. Typical changes quoted are with respect to the tutorial system (UW), the assessment procedures (UW), change of prescribed text (Macquarie), reduction of laboratory sessions (Griffith), reorganization of the content and the sequencing thereof (Griffith) and reduction of content and laboratory exercises (UQ). Others have introduced IT as a supplementary teaching aid in terms of placing assignment answers, lecture notes and past exam papers on the web – with a longer term view to servicing projected distance education opportunities (UC) and Uof SA has introduced ‘on-line’ homework exercises. UN has restructured the organic section of the course to include an applied organic emphasis.

Q7 Is your Chemistry 1 course a ‘stand-alone’ course or is it a ‘service course’ or a combination of both?

In general, it is apparent that the traditional, stand-alone Chemistry 1 course, specifically designed for chemistry majors, is the minor component of Chemistry 1 programs. The Chemistry 1 courses have primarily become service courses in most chemistry departments surveyed. It is generally assumed that chemistry majors, progressing to the Chemistry 2 program, will naturally emerge from the cluster of Chemistry 1 courses offered. It is believed that attracting chemistry majors from the Chemistry 1 service courses is directly dependent on the quality of teaching in these
courses. However, there is general concern about the standard of the Chemistry 1 program overall as the service focus increases.

Q8 What is the position and status of chemistry at your university?

Strong, ‘research-based’ chemistry departments (UW, Macquarie, CUT, UQ, UofSA, QUT) command respect of the university whereas, small, less research orientated chemistry units (UC, ECU) report that their position is ‘weak’ and ‘vulnerable’. All responding chemistry departments report a measure of ‘uncertainty’ with respect to their future within the faculty and the university generally.

Q9 How is the structure of your Chemistry 1 course(s) determined and what are the important considerations involved?

In general, the structure of the Chemistry 1 course is determined by conformity with best (unilateral) practice and research findings in teaching and learning (UW). The course is founded on strong laboratory skills, training and awareness of OH&S and computer-assisted learning (UC, ECU). The course is structured to maintain a balance between high standards and an acceptable pass rate (UN) and aims to continuously improve the effectiveness of teaching and quality of passing students (UofSA). It is important to review the Chemistry 1 course structure frequently, at least biannually (Macquarie).

Q10 How do you attempt to attract more chemistry students?

A variety of responses eventuated including ‘vigorously promote a ‘self-paced’ style course to commencing (science) students’ (UofSA); ‘reduce the workload, degree of difficulty and raise the profile of chemistry by selecting exciting applications’ (UQ); ‘increase science student intake thereby increasing the Chemistry 1 intake’ (UC); ‘strongly support the RACI chemical education initiatives and activities in schools and interact with local schools and the media in terms of promoting chemistry (Griffith, Flinders); ‘offer double degrees eg Forensic Science/Chemistry co-major’ (Flinders, CUT); ‘enhance the instrumental emphasis of the laboratory exercises’ (CUT); ‘create a caring/nurturing learning environment for students by offering access to teaching staff outside of teaching sessions’ (ANU); ‘maintain a high pass and rate and offer chemical magic shows to local primary and secondary schools and at Year 12 school visits and University Open Days’ (UN); ‘sustain a high quality teaching performance in Chemistry 1’ (Macquarie); ‘attend school Career Nights, advertise the course extensively in the local secondary school
network, visit local industries to attract employees to upgrade their science qualifications and liaise with school Careers Advisors’ (ECU). Most responding departments are complimentary towards the RACI Chemistry promotion posters ‘Not all Chemists wear White Coats’ and ‘Chemistry Nobel Prize Winners’ – which are displayed on departmental notice boards. It is also believed that commencing science students need to be provided with quality handouts, information literature on the department and on the Chemistry 1 course at enrolment.

Q11 What is the minimum knowledge base of your Chemistry 1 course?

Most responding departments welcomed a pass in HSC Chemistry for Chemistry 1 enrolment but this is not a requirement (UN, Flinders, UC). It is recognized that a ‘nil chemistry’ background is rapidly becoming the ‘norm’ for Chemistry 1 enrolment (UofSA, Griffith). However, some departments still require a pass in HSC Chemistry for enrolment into Chemistry 1 (Macquarie, ANU, UQ) and others work on the basis of the ENTER score only (CUT).

Q12 To what extent are students involved in the learning process and do you have an interactive tutorial program as an adjunct to the Chemistry 1 course?

Typical responses were: ‘students are highly involved since it is a defining feature of the self-paced learning system’ (UofSA); ‘we have a computer-managed self-testing tutorial scheme (5 tests per semester)’ (UQ); ‘we do not mark tutorial assignments or laboratory reports. Students mark these via web-provided answers’ (UC); ‘the tutorial system is recognized as an integral and essential part of the course’ (Griffith, ANU, Macquarie); ‘we have a drop-in, non-compulsory, strictly informal tutorial system’ (Flinders, ECU) and ‘we offer computer-generated individual assignments to each student (5 per semester) – these are self-paced and self-assessed’ (UW).

Q13 What are the minimum expectations of students at the end of the Chemistry 1 course in terms of basic knowledge and manipulative skills?

Most responding departments expect some proficiency in chemical basics, chemical literacy: communication, written and interpretation, experimental skills, principles of OH&S as applied to chemistry, basic mathematics and problem-solving skills and self-learning skills using the prescribed text (Griffith, UQ, UC, ANU, UW, UofSA, CUT).

Q14 What is the role/function of textbooks in your Chemistry 1 course?
Typical responses were: ‘textbooks are heavily used by virtue of the course structure’ (UofSA, Flinders, Macquarie) ; ‘we use one ‘General Chemistry’ text in conjunction with a separate ‘Organic Chemistry’ text’ (UQ, ANU, UN, CUT) ; ‘we supply a ‘work book’ and lecture notes on the web’ (UC) ; ‘we supply course notes’ (Griffith, UN) and ‘we use textbooks (in the library) as a reference source only’ (EC, UW). There was general agreement that despite the extensive range of Chemistry 1 textbooks available, no single text satisfies the needs of an Australian tertiary Chemistry 1 course, particularly with respect to the organic chemistry component.

Q15 Are any ‘hand-out’ notes supplied in the Chemistry 1 course to explain/expand/support the prescribed text?

Typical responses were: ‘supporting materials are in the library and on the web’ (UW) ; ‘a study guide is provided together with an ‘in-house produced’ CD Rom’ (EC); ‘supporting materials are produced and sold by the University Bookshop (Macquarie) ; ‘a printed version of the Power Point (lecture) slides is provided’ (UN) ; ‘full course notes are provided’ (ANU, UQ) ; ‘full course notes are on the web’ (Flinders) ; ‘tutorial problem sets with answers and laboratory report templates are available’ (Griffith) ; ‘the notes provided are regarded as supplementary to the prescribed text’ (UC) and ‘full notes are provided for the organic section of the course in lieu of a suitable text’ (UofSA). A general reluctance to provide full course notes was apparent in view of subsequent reduced class attendance rates.

Q16 How do you attempt to show the richness/diversity/cohesiveness of chemistry at the Year 1 level?

All responding departments indicated that the richness, diversity and cohesiveness of Chemistry were critical ‘interest factors’ of the course and their inclusion was achieved by ‘research laboratory tours and offering assignments or mini-projects on a student chosen chemical topic’ (UofSA) ; ‘use of inspiring examples and applications and making frequent reference to the rich history of chemistry’ (UQ, ANU) ; ‘by passionate, enthusiastic teaching’ (UC, Flinders, Macquarie) ; ‘by ensuring a logical content sequence and by linking a topic to those previously discussed and to those to be discussed subsequently’ (UC) ; ‘by having lecture demonstrations and chemical magic shows’ (UN) ; ‘by giving examples of ‘chemistry’ in other sciences so as to reveal the ‘enabling aspect’ (Griffith) ; ‘by giving real-life examples, such as given in ‘Atkins’ Molecules’ (Griffith) and ‘by
revealing the diversity of applications and the diversity of the chemical sciences so as to show the breadth and depth of chemistry and that it is not a single science’ (UN, UW).

Q17 What is the method of assessment of your Chemistry 1 course?

Some responding departments have 4 (Macquarie, UW), some have 3 (UQ, Flinders, UN, Griffith) and others have 2 (ANU, ECU, UC) assessment components but all have a final examination constituting at least 50% of the overall assessment. Only UofSA offers an optional final examination as part of its Keller-style assessment process. It was noted that the final examination is still believed to be an essential element so as to maintain a significant overall course standard.

Q18 Is there scope in your Chemistry 1 course for students to follow up on their specific interests and how is this allowed for?

Responses varied from simply ‘no’ to ‘flexible initiatives’ including: ‘a mentor scheme is in place for Chemistry 1 students and all staff are involved’ (UW); ‘through informal interaction with staff and their research interests’ (UN) ‘via encouragement of extended reading’ (ANU) and ‘special projects are available for students who complete the (Keller) modules ahead of deadlines’ (UofSA).

Q19 How are multimedia and IT teaching methods used in the delivery of your Chemistry 1 course?

Most responding departments reported an increasing use of ‘technology’ in the teaching and delivery of Chemistry 1. Some initiatives were: ‘extensive web usage for lecture notes, tutorial and assignment answers and past exams’ (UC, Macquarie); ‘we use computer-based tutorials’ (UofSA, Macquarie); ‘all our lectures are delivered by Power Point with some inclusion of videos and animations (UQ, Flinders, UN, ECU, Griffith, UN, Macquarie)’; ‘our pre-laboratory tutorials are delivered by CD Rom (CUT, UW)’; ‘students have email access to Chemistry 1 lecturers (UN)’; ‘we have established a Chem.1 website inclusive of ‘chat rooms’, forums, practice exercises, worked examples, past exam questions and lecturer email communication’ (UW) and ‘5 assignments are e-mailed to each student during the course which are computer marked (UN).

It was noted that these responses gave the ‘1999 picture’ with respect to use of IT in teaching Chemistry 1 but that IT teaching methodology was becoming increasingly popular.
Q20  Is ‘self-paced’ chemistry learning via CD-Roms and the internet part of your Chemistry 1 course strategy?

Most departments responded ‘No’ and were not in favour of use of the internet to provide definitive chemical knowledge. However, most were in favour of use of CD-Roms to supplement the course content (ECU, Macquarie, Griffith, UN, CUT, UofSA, UQ, Flinders). It was generally accepted that computer-based learning aids in chemistry need to be applied with a measure of caution and are not a substitute for conventional face-to-face teaching methodologies.

2.5 IMPORTANT OUTCOMES

The universal conclusion from the interviews is that Heads of Departments of Chemistry are concerned about the future status of chemistry in Australia about the future of chemistry in Australian Universities and believe that there is an urgent need to address the serious decline in interest in chemistry as a central science, particularly at the secondary/tertiary interface. Discussions with the Heads of Chemistry Departments indicated that it is critical to point out to Chemistry 1 students early in the course that the most significant future advances in science will be at the molecular level and ‘chemistry’ is the indisputable ‘molecular science’. Perhaps equally important, Chemistry 1 lecturers have to recognize that in general, they are not teaching chemistry students to be professional chemists and hence, somewhat reluctantly, have to recognize that the traditional content of the Chemistry 1 course and the traditional methods of teaching it are not entirely appropriate for the required dynamic and captivating Chemistry 1 course of the 21st century. Thus, chemistry needs to be made a more flexible subject from Year 1 onwards thereby allowing students with a coherent chemistry base knowledge to ultimately choose a wider range of science-based careers. Such a vision is imperative if quotas for Year 1 science students are to be maintained and Departments of Chemistry in Australian Universities are to remain viable.

The interviewees are generally agreed that the Chemistry 1 course has to be ‘softened’ with respect to inclusion and usage of mathematical concepts. This inevitably presents a challenge in terms of retaining a high course standard. New ways will have to be found to present and teach physical chemistry which rely on less mathematical rigour. [This challenge is addressed in Chapter 8 with respect to new
ways of teaching ‘chemical thermodynamics’ at the Year 1 level.] Likewise, new ways will have to found to teach analytical chemistry involving new presentations of the concepts of ‘precision’, ‘accuracy’ and ‘sensitivity’ – which are all core concepts in analytical chemistry but require enhanced mathematical skills for contextual understanding. The inclusion of organic chemistry in Chemistry 1 will have to be re-assessed and the way that systematic organic chemistry is taught at this level, based on the reactivity of functional groups, will have to be re-assessed. This is necessary in view of the fact that the biochemists, who insist on a robust organic component in Chemistry 1, are equally insistent that the chemistry of bio-organic systems is not entirely dependent on the reactivity of the inherent functional groups.

The interviewees are generally agreed that the elements of ‘relevance’, ‘benefits’ and ‘green (or environmentally friendly) chemistry’ should be included in a Chemistry 1 course but in appropriate contexts and at appropriate levels of intensity. Also, the course should be enriched by appropriate references to ‘chemical history’ and ‘chemical philosophy’.

There is a continuing debate within chemistry departments relating to a ‘core of knowledge’ and an ‘experimental skills set’ in the Chemistry 1 course together with an acknowledged need for a ‘unilateral (national) benchmark curriculum’ for the course and the need for unified quality assurance criteria. In attempting to constructively respond to these issues, a draft paper entitled ‘Quality assurance and recommended targets in the Australian University Chemistry 1 course’ was prepared in early 2000, summarizing previous (additional) informal discussions with Heads of Chemistry Departments and Chemistry 1 course coordinators on the aims of the course, core chemical knowledge and skills acquired, including generic skills, assessment and performance criteria and quality assurance criteria for a Chemistry 1 course and this paper is given in Appendix 3. This paper was subsequently circulated to Heads of Chemistry Departments (in 2000) for discussion but agreement on its adoption has never been attained and hence its status remains as a draft discussion paper but the content is still believed to be relevant and topical with respect to on-going restructures and re-evaluations of the Chemistry 1 course.

A related debate focuses on whether the four traditional sub-divisions of chemistry should be retained in the Chemistry 1 course or whether ‘chemistry’ should be presented as a unified enabling science. The University of Adelaide has adopted the latter approach in the redesign of its Chemistry 1 course (Crisp, 1999) whereby
new flexible paradigms of learning and teaching are applied based on ‘new (teaching) technologies’, the ‘dynamic nature of chemistry’ and ‘external expectations’ of chemistry students. This new approach to the structure and presentation of the Chemistry 1 course is further discussed in Chapter 3.

Both the interviews and the questionnaire responses indicated that it is inevitable that the emerging (IT-based) teaching methodologies will be progressively integrated into the delivery mode of Chemistry 1. It is believed that these technologies, especially ‘interactive multimedia’ can be used to advantage especially to enable visualization of difficult concepts such as molecular architecture, chemical reaction mechanisms and energy transitions. Further, IT-based teaching and learning offers unprecedented opportunities for ‘distance education’, thereby increasing Chemistry 1 enrolments with a consequential strengthening of Chemistry Department operating budgets. However, the already apparent ‘virtual classroom’ deficiencies have to be fully recognized and remedied if the IT revolution in teaching and learning is to be unilaterally effective. It was agreed that progress and change is endemic but with appropriate planning, these powerful vectors can be used to advantage in terms of restructuring the Chemistry 1 course.

It was most apparent from the interviews that departments of chemistry need to be much more aware of the chemical education developments that have taken place overseas and to be more informed with respect to the global chemical education debate. Many more academic chemists should be directly involved in chemical education, not only at the Chemistry 1 level, but as a primary research commitment. It is apparent from this research that if the ‘Chemistry 1 problem’ is to have a chance of serious resolution, educational theory in conjunction with an emphasis on ‘learning’ rather than on ‘teaching’ techniques must be the foundation philosophy of the course. It is apparent that the essential ‘willingness factors’ are already present in chemistry departments to address the dire state of chemistry in Australian Universities but leadership is necessary to invoke change and such leadership can only be effective if it is based on ‘informed’ chemical educational scholarship. This present research project recognizes this deficiency and is designed to provide a structured remedy based on educational research methodologies applied within a global chemical educational environment which is proposed and discussed in Chapters 6, 7 and 8.

A further revelation of the interviews was that the interviewees tend to focus on a range of ‘external factors’ in rationalizing the crisis currently facing chemistry in
Australian universities. Factors such as budget constraints, concomitant staff reductions, the ‘encroachment’ impact of the biological sciences, the quality and impact of science teaching in secondary schools and the poor public image of chemistry are all frequently quoted as ‘core contributors’ to the problem. There is a distinct tendency not to address the contributing ‘internal factors’ such as a lack of recognition of the importance of chemical education as a departmental research strength and its impact on the teaching of chemistry and more importantly in the context of Chemistry 1, the ability of chemical education to address the nexus between ‘learning’ and ‘teaching’ in chemistry. Since so many constraints were highlighted and amplified in the interviews and to some extent in the associated questionnaires, these are discussed in detail in Chapter 5. An important perceived outcome of this research is essentially to provide a basis whereby Heads of Chemistry Departments can rise above ‘external factors’ and recognize the critical ‘internal factors’ which this research has revealed directly affect reform of the Chemistry 1 course.

The interviews and the associated questionnaire responses collectively provide a compelling case for reform of the Chemistry 1 course to (at least partially) address the Australian university chemistry crisis. In particular, the composite responses to Questions 4, 12 and 15 provide a platform for (urgent) reform of the Chemistry 1 course and a basis for the ‘Theoretical Statement’ of Chapter 7. However, the answers to Questions 9, 13 and 15 indicated an incomplete awareness of chemical education developments nationally and these therefore form the basis of Chapter 3 and the responses to Question 14 indicated only a superficial knowledge of chemical education developments internationally and hence these form the basis of Chapter 4. Overall, the interview and questionnaire responses expressed serious concerns about the future of Chemistry 1 in multiple ways which this research has delineated.

Perhaps the most profound postscript message of this research was that the Chemistry 1 course is a most dynamic educational artefact and it will inevitably continue to attract profound interest from scholars of chemical education philosophy. Its progressive development and, more particularly, its restructure is a challenge but is an essential prerequisite in addressing the wider issue of a declining emphasis and role of chemistry in defining Australia’s position in a global scientifically literate community of nations.
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CHAPTER  3

IMPERATIVES FOR REFORM OF
AUSTRALIAN TERTIARY CHEMISTRY

3.1 INTRODUCTION

3.1.1 Purpose

The purpose of this chapter is to review and discuss the most significant issues relating to the reform of chemical education in Australia over the last decade. A case for further reform will be made by briefly examining primary and secondary science education but will be based primarily on an urgent need to reform tertiary chemistry education, particularly at the university Year 1 level. Specifically, the Chemistry 1 course in Australian Universities will be reviewed and set in the context of the overall perspective of the state and status of chemical education in Australia.

3.1.2 Scope and Limitations

Only a few representative studies will be cited to define the present state of primary and secondary science education in order to place tertiary chemistry education in context. This limitation is imposed by the scope of the thesis, as described in Chapter 1. However, it will be shown that such studies are inextricably linked to tertiary science education and the progressive reform of primary, and in particular, secondary science education intuitively forms a basis for reform of tertiary science education.

With respect to tertiary chemistry education, the implied constraints, as revealed by the interviews with Heads of Departments of Chemistry impacting on and retarding reform of the Chemistry 1 course, will be examined. Fundamentally, the interview outcomes discussed in Chapter 2 tended to relate the problems associated with Year 1 Chemistry as inherited from an inadequate chemistry foundation at the pre-tertiary level. Teaching methodologies and learning outcomes associated with secondary science education will thus be examined in order to explore the viewpoints revealed by the interviews.

3.1.3 Expected Outcomes

The interviews with Heads of Departments revealed a range of concerns with tertiary chemistry education and an acceptance of the need for reform, particularly at
the Year 1 level. The imperatives for reform are discussed in detail in Section 3.5 and have a direct impact on the construction of a framework for reform developed in Chapter 7 and, in particular, illustrate the need for reform of the Chemistry 1 course. The Conclusions to Chapter 3 summarize the key factors which drive this reform process and these are used as a basis for the derivation of the theoretical framework.

3.2 THE ‘BIG PICTURE’ DILEMMA

A recent DEST – commissioned report entitled: ‘Cleaver Teachers, Cleaver Sciences’ (Lawrance, Palmer, 2003) quotes Australia’s Chief Scientist, Dr. Robin Batterham:

Excellent teachers are the key to exciting and sustaining interest in science in schools. (p.42)

and:

Australia’s success as a knowledge economy is dependent on a highly skilled, informed and scientifically literate workforce who receive a strong foundation of SET (science, engineering and technology) knowledge throughout their primary and secondary schooling. (p.43)

The report identifies the critical relationship between science education and the national economy:

The growing recognition of science, mathematics and technology as the keys to a reinvented national economic future sets an agenda for the immediate future around which a vision for (science) education can be built. (p.43)

A recent report on ‘The Status and Quality of Teaching and Learning of Science in Australian Schools’ (Goodrum et al., 2000) proposes an ideal picture of contemporary school science in terms of a set of themes:

The classroom environment: Excellent facilities, equipment and resources to support teaching and learning and class sizes that make it possible to employ a range of teaching strategies and provide opportunities for the teacher to get to know each child as a learner and give feedback to individuals.
The curriculum: Should be relevant to the needs, concerns and personal experiences of students. Science and science education are valued by the community and must have high priority in the school curriculum.

Teaching and Learning: The teaching and learning environment should be characterized by enjoyment, fulfillment, ownership of and engagement in learning and mutual respect between the teacher and students. Teaching and learning should be centred on inquiry. Assessment serves the purpose of learning and is consistent with and complementary to good teaching.

Teachers: Teachers should be supported, nurtured and resourced to build the understandings and competencies required of contemporary best practice. Teachers of science with a recognised career path based on sound professional standards should be endorsed by the profession. Science teaching should be perceived as exciting and valuable, contributing significantly to the development of persons and to the economic and social well-being of the nation. (p.3)

A more emotive statement about the state of science education in Australia, especially its inability to produce sufficient numbers of trained scientists to meet the needs of a ‘knowledge-based’ economy in the 21st century was published as a joint statement by four of the leading professional science societies in 2001 entitled ‘National Initiatives in Education: A joint statement by the RACI, AIP, AMSC & IEA’, (2001) (Appendix 1). This statement was discussed in Chapter 1 as being a major driver for reform of (enabling) science education in Australia because of its compelling core message directed at the Federal Government that the -

(provision of high quality training and a stimulating and rewarding career environment for teachers at all levels of education, together with allocation of resources to the education sector that ensures education of students in the ‘enabling sciences’ at the highest international standard (p.4)
- is essential if the predicted worst scenario of zero enrolments in the enabling sciences at the secondary and tertiary levels by 2020 is to be avoided.

This potential crisis is compounded by a decreasing proportion of trained science teachers particularly at the secondary level (Lawrence and Palmer, 2003) and a parallel decrease in attraction of students into Year 12 and tertiary Year 1 basic science courses (Dobson, 2003). Thus, the national aspiration and the national trend with respect to science education are mutually opposed and hence reform of the overall science education system is highlighted as a national priority.

Australia is not unique in aspiring to ‘clever country’ status but the current science education issue suggests that governments in Australia are not sufficiently visionary to appreciate that in a world of accelerating technological change, a ‘clever country’ needs to be achieved by a progressive and well-resourced national science education system. If Australia is to achieve ‘clever country’ status in a global community of nations facing endemic technological change, then it will need to produce significantly more trained scientists in the next decade – as succinctly stated by Queensland’s Chief Scientist, Professor Peter Andrews (Sydney Morning Herald, 2004):

> Australia needs an additional 75,000 scientists by 2010
> if it is to meet the demands of a ‘knowledge economy’. (p.4)

This will require a greater commitment by Government than that stated in ‘Backing Australia’s Ability’ (The Australian Government’s Innovation Report, 2003-2004):

> Innovation has always been at the heart of the way Australians have adapted and succeeded on this island continent. As we look to our future in an increasingly globalised world, innovation remains central to our prosperity. The Australian Government’s $3 billion innovation statement ‘Backing Australia’s Ability’ is generating real results and real jobs by supporting the creation, development and implementation of new ideas. Science and innovation is now one of the government’s strategic priorities, further strengthening our commitment to Backing Australia’s Ability. (p.1)
Present indications are that this ‘proud tradition of innovation in science’ is not sustainable. It is a sad fact that despite progressive changes in the primary and secondary school science education over (at least) the last 3 decades, enrolments in science and mathematics at the senior secondary school level have significantly fallen. This is verified by a study undertaken by the Australian Council of Deans of Science (Dobson, 2003) which reports that over the period 1989 to 1997 -

(1)ooking more narrowly at (school) students enrolled in science courses, apart from the biological sciences, the greatest growth has been in non-science/non-Information Technology subject disciplines. For science students, their overall interest in mathematics and physics has been in decline since 1993 and in the earth sciences and chemistry, the rot set in 1997. Biological sciences and ‘other sciences’ (such as psychology) both had their best year in 2002. Overall analysis of Year 12 subject enrolments in science indicate that the decline noted in the 1980’s has continued into the 1990’s. (p.83)

Although our present society is founded largely on the achievements of science, fewer young people perceive the sciences as a career path. The consequences of this for a nation beset on a technologically advanced future course are of great concern. It is apparent from the Australian Council of Science Deans study (Dobson, 2003) that the present science education system in Australia is not engaging students in science and creating and nurturing an interest in science at an early age to permit the development of familiarity, skills and interests that may lead to a positive choice to pursue a science-based future career. This fact was highlighted by an article in the Education Age entitled ‘School Science in Crisis’ (Cross, 1995) which asserted:

*The crisis of the revolt against the physical sciences by students in secondary schools is obvious - university places are not being filled and physics and chemistry lie near the bottom of students’ choice for further study.* (p.12)

This engagement task is pivotal on teachers in primary and secondary schools although the professional scientific societies and science-based industries can play a supportive role, particularly in identifying challenging, exciting and rewarding science-based career paths and this has been recognized by Bishop (1998) -
(b)ut in the last resort, if our education is to get better it will get better because it is carried on by more educated, more sensitive and more human people who are not afraid to emphasize the social and moral relevance of what they teach. (p.114)

This leads to a further aspect of the science education dilemma, the deficiency of the system in ensuring a scientifically-literate society able to underpin and drive the ‘knowledge nation’ ambition. Hence, teachers skilled in the enabling sciences and mathematics and simultaneously skilled in engaging students in learning in these fields, will become increasingly important in satisfying the national need for a comprehensive broad-based education inclusive of the sciences. Teacher preparation must therefore address both the specialist and generalist teaching of science, mathematics and technology in primary and secondary schools if scientific literacy of Year 12 science students is to be enhanced. Thus, the school teachers of 21st century Australia carry the responsibility of delivering empowering science courses which sustain a technologically highly scientifically-literate society as has been emphasized by Bishop (1998):

We need more and better teachers. The only solution I can offer is as difficult to achieve as it is to state. We delude ourselves if we think that new techniques can ever be more than aids – necessary, valuable, but still aids. We delude ourselves if we believe that unlimited research in education will provide a series of simple answers for education in the new world, though some research is necessary. (p.114)

With such reliance placed on science teachers for generating and sustaining a scientifically-literate society, it is necessary that the training of these teachers is of the highest standard. However, in this context, there are numerous shortcomings. There are shortages of science, mathematics and technology teachers that may be approaching critical levels in some regions. This has been recognized by Power (1980) with respect to the teaching of chemistry in secondary schools:

The lack of chemistry background of many school science teachers has led to an increasing emphasis on the biological sciences in many schools. (p.20)

Thus, there are probably teachers who are teaching science subjects outside their range of expertise. This is a real problem with Years 11 and 12 Chemistry,
which may be taught by teachers whose speciality is general science or biology. Further, ‘teaching’ has a low profile as a career and the status of the teaching profession in general is questionable. The demands on science teachers are very significant such that in addressing a comprehensive coverage of the prescribed curriculum within a defined time-frame, ‘scientific literacy’ has to be assumed to ‘evolve naturally’ as a consequence of the adopted teaching methodology. Power, 1980, has summed this up very well to the way that chemistry is taught in schools:

Until we begin to teach chemistry in such a way that the way in which we teach becomes ‘personal knowledge’ rather than ‘school knowledge’ then what we teach is likely to be rejected as too difficult or too irrelevant by the masses. The materials we now use virtually guarantee that the majority of our students will leave school believing chemistry is a dull, abstract and difficult subject which has nothing to contribute to their lives either by way of enhancing their capacity to cope with their technological or natural environment or by way of opening up new vocational opportunities. (p.18)

Scientific literacy is a major study area in its own right. Leading authorities on scientific literacy such as Fensham have devoted their entire academic career to this facet of science education (Cross, 2003). Similarly, Cross has adopted Fensham’s theme of ‘Science for all’ in his recent books (Cross, 1996), (Cross and Price, 1992) and (Cross and Fensham, 2000). Despite an extensive literature on scientific literacy, there is still considerable debate (globally) as to its intrinsic meaning (Jenkins, 1990: Eisenhart, Finkel and Marion, 1996: Galbraith et al., 1997). Some regard scientific literacy as the capacity to read with reasonable understanding, lay articles on scientific and technological issues published in newspapers and magazines. Others regard it as being in possession of the knowledge, skills and attitudes deemed necessary for a professional scientist. The more ambitious, such as the American Association for the Advancement of Science (AAAS) in an article entitled ‘Science for all Americans’ (AAAS, 1989), attempt to include both definitions thus defining a scientific literate person as -

(o)ne that is aware that science, mathematics and technology are inter-dependent human enterprises with strengths and limitations:
   is familiar with the natural world and recognizes both its diversity
and unity and uses scientific knowledge and scientific ways of thinking for individual and social purposes. (p.4)

Also, this article directs attention towards scientific literacy for a more socially compassionate and environmentally responsible democracy when it is stated that:

Science can provide knowledge to develop effective solutions to its global and local problems and can foster the kind of intelligent respect for nature that should inform decisions on the uses of technology without which we are in danger of recklessly destroying our life-support system. (p.6)

Fensham, 2002, has called for a radical rethinking of the concept of scientific literacy and who should define it. This discourse is both distinctive and provocative and challenges both the meaning and significance of scientific literacy in modern science education. Fensham commences his discourse with the profound statement:

Scientific literacy is too important to leave to scientists and science educators. (p.9)

In the context of this research can be interpreted as ‘chemical literacy is too important to leave to chemists’ and this deduction has important ramifications in the design of a curriculum framework for Chemistry 1 as detailed in Chapter 7.

Fensham has pioneered and promoted the ‘science for all’ concept in science education (Fensham, 1999) and there is now much evidence that school science is designed to benefit all students and not just those who may take up scientific careers. However, it has been pointed out (Solomon, 1997) that when scientific literacy is accepted as a goal to be achieved through primary and secondary school, two questions must be addressed -

(w)hat does this mean for school science?

(w)hat content should be taught in school science? (p.151)

There has been much parallel debate about the meaning of school science and its appropriate content (Bybee, 1997) but, as revealed in the interviews with Heads of Chemistry Departments (Chapter 2), there has been little if any substantive debate about scientific literacy and its meaning and significance in the tertiary Chemistry 1 course. It would seem that academic chemists are not familiar with the concept or the debate.

Fensham (2002) discusses the meaning of scientific literacy in terms of an ‘equation’: Knowledge + Application + Social Interaction = Scientific Literacy.
Fensham believes that social interaction in this context leads to ‘scientific citizenship’. It is the ‘social interaction’ term in the equation which identifies a new driver and gives a new meaning of ‘scientific literacy’. Fensham argues that the school science curriculum in the past has traditionally been devised by ‘scientist educationists’ with an emphasis on preparing bright students to become scientists. A ‘science for all’ approach to pre-tertiary science education should be inclusive of a broad school science curriculum constructed by societal experts coupled with an education program for school science teachers on the social aspects of science. The Fensham thesis represents a major paradigm shift in the meaning of ‘scientific literacy’ which is strongly endorsed in the recent books of Cross et al., (1992 and 2000).

The interviews with Heads of Departments of Chemistry in 1999 indicated that there was general belief and concern that scientific literacy of Year 12 students had not been achieved and perhaps this was a factor deterring students from tertiary science study. The pioneering work of Fensham on scientific literacy has shown that this deduction may be valid due to an inadequate school science curriculum which does not deliver a ‘socially focused’ scientific literacy platform. Hence it is vital to include such a platform in a re-structured curriculum framework for the Chemistry 1 course, as discussed in Chapters 6, 7 and 8.

Fensham, 2002, concludes his discourse on ‘new drivers for scientific literacy’ by identifying two types of school science: science for all future citizens and science for possible future scientists. There is an important analogy with Chemistry 1 courses. This research has indicated that there are two broad groups of students: the main group needs a basic knowledge of chemistry but will not study chemistry beyond Year 1 and the smaller group may continue with chemistry as a major component of their degree. It is therefore instructive to use the Fensham soccer ball/school science curriculum analogy as in insight into a scientific literacy pathway for the Chemistry 1 course. A soccer ball has an ‘inside’ and an ‘external surface’. The former can be thought of as ‘scientific knowledge’ and the latter as the interaction medium between scientific knowledge and society. The surface of the ball is a ‘permeable (knowledge) membrane’ with two-way knowledge transfer. It is the responsibility of the science teachers to direct such knowledge transfer. This powerful analogy gives added momentum to science education. It is particularly relevant to the Chemistry 1 course,
since it uniquely provides a ‘scientific literacy empowerment’ strategy for incorporation into the curriculum framework.

3.3 PHILOSOPHICAL DEVELOPMENTS IN CHEMICAL EDUCATION AT THE PRE-TERTIARY LEVEL

The major trends in chemical education in Australia up to 1980 have been reviewed and critically discussed (Power, 1980). It is argued that many of the problems which have beset pre-tertiary chemical education have been focused on the curriculum and the inability of successive generations of science educators to structure a chemistry school curriculum which empowers students to relate to a technological age. Power argues:

Curriculum development in chemistry involves political processes of social judgement as well as questions about what can be taught, how and when. Thus the shape of (school) chemistry courses is very much a function of the strength of pressure groups inside and outside the profession. These groups materialize their value positions regarding what knowledge, skills and attitudes count and what constitutes good teaching in public demands on schools. (p.15)

Power concludes:

Unless there are substantial improvements in the quality of the curriculum materials at the Junior high school level and in the quality of chemistry teaching at the classroom level, one cannot hope for a brighter future (for chemical education in Australia). (p.22)

and:

What does seem to be needed is a pooling of the science education resources of universities, industry, science teachers’ associations and the schools in order to tackle the problems from within, rather than the faint hope that the next curriculum package will eliminate all problems. (p.22)

In the subsequent two decades, it is the social demands and the associated scientific literacy movement which have preferentially shaped the content of chemistry courses in schools (Fensham, 1991) rather than the ‘cooperation’ incentives
which Power had hoped for. A parallel but not so powerful influence has been the incorporation of the History and Philosophy of Science into science teaching. However, Erduran and Scerri (2002) imply that -

(s)cience education is not doing enough to align science teaching with contemporary perspectives in the philosophy of science.

and:

Science needs to be connected to its social and historical roots. (p.7)

In this context, in a recent PhD study, McColl (2002) has discussed a curriculum design framework for science education based on the history of science which uses ‘physics’ as an exemplar for school physics education. McColl identifies that:

The development of a clearer understanding of science and its processes needs to be incorporated into science education programs at the secondary level, if attempts to adopt the current scientific literacy goals are to be taken seriously. The process requires the development of an awareness of the many aspects which characterize the nature of science, illustrated by reference to particular instances. In practice, this could take the form of a case study of the history of some field of science, with emphasis on the features which illustrate the philosophy, sociology and methodology of science in the construction of scientific knowledge. (p.93)

Hence, McColl is suggesting that the ‘nature of science’ and ‘history of science’ are inextricably linked and that science teaching at all levels must recognize this synergy. However, the ‘history and philosophy of chemistry’ has not traditionally been included in chemistry curricula in schools and it is relevant to note that the ‘scientific literacy’ and ‘history and philosophy of science’ influences have had little effect on tertiary chemical education, as will be discussed in Section 3.4. A most significant outcome of the Heads of Chemistry Departments interviews was a general lack of knowledge by chemistry academic staff of developments both nationally and internationally in chemical education and hence a lack of awareness of the agenda for reform of chemistry teaching incorporating the social and philosophical aspects of chemistry. In fact, the philosophy of chemistry is an emerging field and has the potential to inform and guide chemistry education particularly through insights into the nature of chemical knowledge. In this context, the Australasian Association for History, Philosophy and Social Studies of Science (AAHPSSS) conference, held in
Melbourne in 2001 did much to promote the history and philosophy of science as a major paradigm in modern teaching methodologies. In particular, a paper by Rae (2001) entitled ‘Chemistry in Australia – Growing Up Down Under’, succinctly identified that progress in the teaching and learning of chemistry (at all levels) can only be achieved by acknowledging and understanding the key developments of chemistry in the past so as to be able to understand the structure of chemical knowledge.

It is instructive to discuss further these two influences on the development of pre-tertiary chemical education since some important implications for tertiary chemical education become evident. As reflected previously, Fensham has consistently pioneered a ‘science for all’ philosophy as a cornerstone of science education at all levels (Fensham, 1985). In this context, it is important to decide why a science education is important and ‘who’ it should be designed for. It is Fensham’s belief that the science education received by the majority of the school population should be different to that received by the minority who continue to study science at university. This basic philosophy must lead inevitably to an improved level of scientific literacy for school-aged students. However, in Australian schools, curriculum structures and developments thereof have failed to incorporate the ‘science for all’ ethic and hence scientific literacy levels of school students fall far short of those expected (Cross, 1995). A broad examination of this dilemma reveals that in general, pre-tertiary science curricula developments have consistently been dominated by changes to the upper school science curricula, which have a strong conceptual orientation, whereas lower and primary school science curricula have a strong process skills curriculum. Fensham concludes that the overall pre-tertiary science curriculum preferentially favours the minority of school students who may choose a science-based career but does little to provide a measure of scientific literacy for all. The message for the future therefore is clear: the school science curriculum content should have social meaning and usefulness for the majority of students and it should enable students to share in the wonder and excitement that has made the development of science such a great human and cultural achievement. The extent to which this message has been noted in the design of current pre-tertiary science curricula will be discussed in Section 3.4. This is also a powerful message for designers of curriculum frameworks for tertiary chemistry courses and particularly for the Chemistry 1 course, as is discussed in Chapters 6, 7 and 8.
‘Teaching science for social responsibility’ has been a theme adopted by Cross and Price (1992) to promote science in schools at both the primary and secondary levels and to promote a science teaching methodology which leads to greater levels of scientific literacy of students. The authors quote as one of the reasons for writing this book as -

(a) growing disenchantment with science among large sections of young people, which may account for the problem of attracting students to become science teachers, particularly of physics and chemistry. (p.1)

Cross and Price argue that the main driver for science curriculum development at the pre-tertiary level is underpinned by the triple emphasis: ‘Science, Technology and Society’ (STS) whereby the dangers to the environment and to human life have brought about demands for teaching science in its social connections. However, they also recognize a dilemma in aligning science with technology and the ever increasing use of technology by governments to address the needs of a restructured economy. Thus, they argue that the school science curriculum should equip all students to adapt to a technological age, not via the teaching of ‘technological literacy’ but via the teaching of ‘scientific literacy’ and this literacy distinction is perhaps the key indicator of a viable science curriculum of the future. It is another strong message for the designers of post-secondary science curricula and, in particular, chemistry curricula, since chemistry can also be conceived as a ‘science for the technological age’, especially since ‘chemicals’ are an integral part of modern society.

It is apparent then that the philosophy of change in science education and hence in chemical education is well-embedded (in principle) in curriculum restructures to ensure a ‘science for all’ outcome together with a ‘scientific literacy’ empowerment. The outcomes and effectiveness of these progressive changes are discussed in Section 3.4. with specific reference to the present science curriculum for Victorian state schools.

3.4 RECENT CHANGES IN PRIMARY AND SECONDARY CHEMICAL EDUCATION

Momentum for reform of the secondary science curriculum in the countries of the developed world has gathered pace over recent decades in terms of ‘outcome
based’ curriculum frameworks. Such frameworks are premised on the assumption that students can successfully learn science in a carefully presented linear progression and will provide students with scientific literacy corresponding to a sufficient level of scientific understanding to cope in the modern world. One such curriculum, introduced into Victorian schools in 1995 and based on the Australian National Statement for Science (Australian Education Council, 1992) is typical of such curricula and is briefly reviewed here, particularly with respect to the chemistry component.

It is recognized a priori that a well-designed school science curriculum helps and encourages students to: develop knowledge and skills central to the biological, earth and physical sciences; apply knowledge of science and understanding of some key scientific theories, principles and ideas to explain and predict events in the natural and physical world; develop and use the skills of scientific investigation, reasoning and analysis to generate or refine knowledge, find solutions and ask questions; develop scientific attitudes such as flexibility, curiosity, respect for evidence and critical reflection and communicate scientific understanding in appropriate scientific languages to a range of audiences.

The Curriculum & Standards Framework (CSF) (Victoria) (Verma, 1995) seeks to encourage the development of scientific and technological literacy, based upon an evaluation of research from the social studies of science, the role of science and technology in society and technological literacy. The CSF attempts to present primary and secondary schools (in Victoria) with a framework for designing a balanced and sequential science curriculum for all students. It is designed to help and encourage students to develop critical thinking skills whilst gaining and appreciation and understanding of essential science concepts. The framework recognizes the progression in student learning outcomes and is subdivided into seven levels, which span eleven years of schooling from ‘Prep Year’ to the end of Year 10. Level 7 is intended to provide extension material for students who have demonstrated achievement at Level 6 and does not duplicate material covered at VCE units 1 and 2. The treatment of the content becomes increasingly sophisticated as the levels ascend, with the inclusion of more complex explanations and models, more involved investigations and an increase in the degree of quantitative work. ‘Hands-on’ exercises and projects are emphasized at all levels so that students experience science and scientific principles. Also at each level, safety procedures and potential hazards
are emphasized. For each level, there are ‘learning outcome statements’ which provide teachers with a guide to the type of evidence which confirms that a student has achieved a defined outcome. The framework has four ‘conceptual strands’ each with its characteristic scientific knowledge and ideas: Natural and Processed Materials, The Physical World, Earth and Beyond and Life and Living. These strands are drawn from the traditional areas of chemistry, physics, earth science and biology and all include major basic (scientific) concepts. Content and processes are strongly linked and it is significant to note in the context of the present research that the ‘traditional sciences’ included in the conceptual strands are effectively the ‘enabling sciences’ which together must intuitively form the conceptual core of an enabling science curriculum from both a teaching and learning perspective.

Chemistry is included in the ‘Natural and Processed Materials’ strand. The ‘Reaction and Change’ outcome is related to the curriculum focus ‘Materials: Structure, Properties and Uses’ and these outcomes range from being able to ‘identify and describe changes in materials’ at Level 1 (Prep. Year) to ‘describing energy changes in chemical reactions and changes of state; describing chemical changes using chemical symbols and discussing the characteristics, including chemical reactions of groups of similar substances’ at Level 6 (Year 10). The Natural and Processed Materials strand is structured so that students experience chemistry and chemical change in a wide variety of forms over the first 5 levels before being able to describe chemistry and chemical change in the language of chemistry in Level 6 at which the concepts of atoms and molecules are first presented. Thus, it is apparent that the much debated ‘core of chemical knowledge’ upon which the tertiary Chemistry 1 course is based is acquired in Year 10 and this is an essential prerequisite to VCE Chemistry.

There has naturally been intense debate on the (Victorian) Curriculum and Standards Framework since it was introduced in 1995. One such review has concentrated on the teaching of primary science and has been published as a book entitled: ‘Teaching Primary Science – Empowering Children for their World’ (Cross, 1996). Perhaps his most pungent criticism of the CSF relates to its lack of reference to the social responsibility of science over the primary science levels:

*If you are to teach in Victoria you will be teaching using this framework document. It will be a challenge to teach in a socially responsible way.*

\[(p.48)\]
Cross proposes that over the four bands of primary science, an integrated science curriculum should be adopted and discusses in detail a component theme ‘Living in more sustainable ways’ which is strongly based not only on scientific concepts but also on the social responsibility of science (Chapter 10).

In another book ‘Teaching Science for Social Responsibility’ (Cross and Price, 1992), Chapters 6 and 7 develop ideas for ‘Science Schooling for Tomorrow’ which recognize the shortcomings of science teaching in schools -

\[
\text{(p)resentations of science as abstractions divorced from obvious relation to the lived world of the student; as a rhetoric of conclusions, of truths divorced from theory; all of these deprive the students of the excitement and relevance of science to the problems of their time.} \quad (p.102)
\]

A science teaching methodology is proposed which is consistent with social responsibility of science. The latter requires -

\[
\text{(c)hanges in teaching style to emphasise the produced nature of scientific theory and the functions that different kinds of theories serve.} \quad (p.102)
\]

Cross and Price conclude:

\[
\begin{align*}
\text{Teaching science for social responsibility is more a matter of the attitude and skills of the teacher than of new syllabuses.} \\
\text{Much can be done within existing syllabuses since, as we have shown above, a majority of these are today demanding ‘relevance’, ‘reality’, ‘teaching from contexts’ and even ‘social issues’. The most common term used however, is ‘applications’ of science, a term which does not accurately reflect the distinction between science and technology nor the social problems with the latter.} \quad (p.103)
\end{align*}
\]

An alternative framework for a middle school science curriculum has been presented by Plant (2000) whereby a small number of key areas are defined that can support the development of scientific literacy for all and can also meet the demands of those students who choose to go on and pursue higher education in science. Three ‘areas’ are chosen ‘Science as part of Society’, ‘The content of Science’ and ‘The Methods of Science’. This structure closely relates to that of ‘Science, Technology and Society (STS). These three areas are then linked to five domains, the concept domain, the process domain, the creativity domain, the attitudinal domain and the
applications domain as previously proposed by Yager (1992). Plant then compares the CSF with his alternative framework and concludes that -

(t)he (CSF) aims are too narrow and focus on technical knowledge, missing an emphasis on the big ideas of science and excluding the social goals of science education, critical to the public understanding of science. Secondly, the grid maps of student outcomes are too broad and detailed, leading to curriculum ‘over-stuffing’, it assumes that students can learn all of science in carefully planned steps and in linear progression. Thirdly, process skills of science are not stressed leading to concerns of content laden courses and a lack of emphasis on the wonder and excitement of science. Fourthly, the CSF lacks linkage between technology and science, thereby encouraging a narrow view of science and not correctly preparing students for future citizenship where technological know how is crucial. The CSF does not meet the requirements of providing scientific and technological literacy. (p.177-8)

These in depth reviews of secondary science clearly show dissatisfaction with current school science curriculum frameworks and project a powerful message in terms of the way forward for school science is via a socially critical science curriculum framework. This message has been reinforced in subsequent short papers by Cross (1995):

Are our children to be unthinking consumers or socially critical members of society? The latter vision would tend to strengthen democratic participation in the debate about the technologically based society. Such a curriculum would not only focus on the need of people to understand science and technology but it would also mean they would be less likely to stand by passively as society is reconstructed through science and technology. (p.12)

Cross and Fensham (1996) strongly argue that science in Victorian schools does not measure up with the world’s ‘best practice’ because the CSF lacks emphasis on ‘science as inquiry’, ‘science linked with technology’, ‘science in personal and social perspectives’ and ‘the history and philosophy of science’. It is these deficiencies of the secondary science curriculum which need to be addressed in any attempt to restructure the post-secondary science curriculum.
As a postscript to this debate, a veteran scientist, Professor Ian Ritchie, in a published interview with the ‘Weekend Australian’ (2002) has suggested that school chemistry courses need to be simplified in order to enthuse students in science and address the acute shortage of specialist science teachers. He concludes:

*What is desperately wrong from my point of view, is the loss of science teachers in physics and chemistry in schools. The analogy I’m taking is chemistry is becoming extinct, so if we run out of good chemistry teachers, we die. In my opinion, we’ve got to raise the profile of chemistry and physics teaching in a way we haven’t done before.*

(p.3)

In reflective retrospect, it is somewhat inaccurate to summarily conclude that critical stimuli are lacking in terms of activating interest in science at the secondary school level. Encyclopedia such as ‘The Wonders of Science’ (1968) has a section on ‘Chemistry as a Career’ and Lancelot Hogben’s ‘Science for the Citizen’ (1939) is a legendary exposition of the ‘power to shape the future course of events so as to extend the benefits of advancing scientific knowledge for the satisfaction of common human need’—perhaps the original plea for the ‘science for all’ paradigm of science education. There are also contemporary Australian initiatives to enthuse secondary students to pursue scientific studies. (Eastwood, 2002) suggests that -

(t)he basic concepts of science that effect everyday life need to be become more generally understood and that the use of humorous rhymes is one way of communicating science to children. (p.13)

Another initiative is the ‘Chemical Detective’ program run for secondary science students by chemistry academics at Deakin University (Nelson, 2002) aims to engage students with science by exposing them to ‘hands-on’ forensic chemistry via a ‘chemical detective’ lure. This program has highlighted to thousands of Victorian secondary students that science can be an exciting, creative and stimulating area for study. Students and science teachers have agreed that ‘The Chemical Detective’ program hits the mark while engaging students and simultaneously relates to the science curriculum. A further contemporary example of ‘popularising science’ is a ‘talk-back’ radio program ‘Ask Mr. Science’, whereby listeners are invited to put science questions to Professor Nick Klomp of Charles Sturt University on air during his weekly radio programs (Klomp, 2002). Klomp’s aim is -

(t)o enthuse and encourage everyone to become interested in science. (p.23)
It is a sad reflection that perhaps the feature of current science education that is most lacking is the ‘science for all’ philosophy.

Finally in this review of school science, it is relevant to briefly review the Years 11/12 certificate chemistry courses. In Victoria, these correspond to ‘VCE Chemistry’ and consist of four units: units 1 and 2 are taken in Year 11 and units 3 and 4 are taken in Year 12. Each unit deals with specific content and is designed to enable students to achieve a set of outcomes. Each outcome is described in terms of the key knowledge and skills that students are required to demonstrate. The rationale for the curriculum framework of VCE Chemistry (VCE Study Design - Chemistry, 1999) is described thus:

For the majority of students, learning is more effective in the context of the application of chemical knowledge to technology and society. Therefore a thematic approach to chemistry has been adopted, and throughout the study contexts have been provided for the teaching of chemistry; for instance, the recycling of polyethenes, the structure and reactions of detergents and the special significance of water as a solvent. Students will have the opportunities to investigate, explore and solve qualitative and quantitative problems and discuss chemical concepts and issues. Together the four units of the study provide a comprehensive coverage of chemistry at this level. In sequence, the units foster the development of key knowledge and skills and develop and revisit key concepts in a variety of contexts. (p.7)

The learning outcomes are also defined:

This (VCE) course of study (over 2 years) is designed to enable students to- understand the major ideas of chemistry and develop an ability to apply these ideas in both everyday and hypothetical situations-use theoretical models as aids to explaining chemical phenomena and appreciate that such models are subject to constant scrutiny and necessary modification-understand the language and methods of chemistry-develop the practical skills necessary to understand experimental work-explore the wider social, economic, technological and environmental aspects of
chemistry - consider the role of chemistry in other areas of science
- understand the procedures required for the safe use of chemical
equipment and the safe handling of chemicals, both in the laboratory
and in everyday situations.  

Assessment of Units 1 and 2 is entirely school based whereas for Units 3 and
4, it is a mixture of school based (coursework) assessment and Board of Studies
examination assessment. In developing the units, teachers must -

take into consideration the prior experience of students as well as
the resources available within the school. Teachers are encouraged
to explore the local community for resources that would enrich the
course and also to emphasise the pervasive use of chemicals and
consideration of (social) issues related to chemistry. In planning
a course, teachers should incorporate the use of information
technology and multimedia technologies in the learning and
assessment of students.  

It is also recognised that -

laboratory activities are essential to developing an understanding
of chemical concepts. They emphasize both the experimental
nature of chemistry and the generation, collection and evaluation
of experimental data.  

In the context of the present research, aimed at a restructure of the tertiary
Chemistry 1 course, it is critically important to briefly examine the structure of
Victorian VCE Chemistry units as a representative senior chemistry course. In terms
of designing a new curriculum framework for the Chemistry 1 course, it is important
to know the basic concepts of chemistry which are incorporated into the VCE
Chemistry units and the extent to which these are tied to defined learning outcomes
and are empowered by association with the social responsibility of science
philosophy. Such curriculum features of senior school chemistry are of critical
relevance to the design of a new curriculum framework for the tertiary Chemistry 1
course described in Chapter 7.

Unit 1 studies a range of chemical processes and activities via common
materials. The chemical nature of materials is explored through an investigation of
their properties and their modification. Materials ‘in everyday use’ are selected for
study with particular emphasis on water and its importance to life and its use as a
medium for chemical reactions. The application of these concepts to the structures of surfaces and the nature of interactions occurring at surfaces is also included. Unit 2 examines a wide range of chemical reactions with emphasis on the writing of chemical equations and performance of calculations based on them. Appropriate chemical concepts are introduced and students are encouraged to evaluate the environmental impact of human activity on the biosphere. Unit 3 adopts a global perspective of chemistry by examining the large-scale industrial production of selected chemicals. The work of chemists in these industries is highlighted. The concept of ‘quality control’ is introduced via a range of analytical techniques and the important work of analytical chemists is emphasized in this context. Unit 4 addresses the relationship between the production and use of energy in non-living and living systems and illustrates the development of chemical ideas within the context of the Periodic Table.

It is relevant to note that a new VCE Chemistry course is to be implemented for both Years 11 and 12 in 2007 (Sharwood, 2005). Each of the four units which comprise the course will be based on a single theme or, as Sharwood puts it ‘a big-idea of chemistry’. These themes are proposed as ‘The Periodic Table’, ‘Environmental Chemistry’, ‘Chemical Pathways’ and ‘Chemistry at Work’. There will also be increased emphasis on practical work and ‘industry visits’ will be one of the assessment tasks which teachers may use for Units 1 and 2. Sharwood concludes that whereas the proposed new VCE Chemistry course is designed to emphasise the importance of chemistry in daily life and reveal the frontiers of chemistry in each of the four units, most teachers will need professional development to enable them to manage the new course. However, the change of emphasis and the new style of teaching senior school chemistry are welcomed.

It is interesting to note the views of Year 11/12 students on the VCE Science Curriculum and a student has written a delightful essay on ‘A student view of science’ which has been published in ‘Chemistry in Australia’ (2004). In commending science studies, she writes:

"The attraction of science is that it provides answers to questions that would otherwise go unanswered and to those who possess the answers, power is granted." (p.3)
This brief overview of the VCE Year11/12 Chemistry curriculum structure reveals that the essential criteria of teaching and learning are included. In particular, a progression of learning of the fundamental concepts of chemistry, together with application thereof is apparent over the range of the four units. Further, ‘relevance’ is treated in terms of ‘what chemists do’ and the social, economic and environmental aspects of chemistry are addressed and developed through laboratory exercises. It appears that the four units collectively deliver a well-balanced foundation chemistry course that has some of the hallmarks of the ‘science for all’ Fensham vision.

3.5 RECENT CHANGES IN TERTIARY CHEMISTRY EDUCATION

The interviews with Heads of Chemistry Departments conducted in 1999 and discussed in detail in Chapter 2 exposed numerous concerns with the state and status of chemistry in Australia and the need for urgent chemistry education reforms. The personal view of the chemical education enterprise in Australia put forward by Bucat (2001) succinctly identifies many of these concerns. Bucat asks the question:

Does chemistry education deserve a place amongst the fields of study in the discipline of chemistry alongside carbohydrate chemistry, surface chemistry and the like?     (p.12)

He continues:

The American Chemical Society has a policy that every department of chemistry ought to have a chemical education group, but in Australia a recognizable chemical education enterprise has been Cinderella to its more prestigious fields of endeavour.     (p.12)

Bucat recognizes that the task of introducing a level of chemical literacy to a disparate population of students with widely different backgrounds, widely different aims and widely different motivation levels requires specialist chemical education skills and yet in most academic chemistry departments, it is believed either consciously or sub-consciously that these skills ‘come naturally’ and hence chemical education and especially chemical education research both have a low profile in academia. It is just such a group of students which constitute Chemistry 1 cohorts and Bucat argues that the best teachers should teach this course and that -

(g)ood teachers need to be able to transform chemistry knowledge into forms learnable by the students.     (p.14)
This plea is a compelling force for enhancement of the profile of chemical education in academic chemistry departments since the present deficiency of chemical education research may be one of the most important factors contributing to the progressive demise of chemistry in Australia.

(Bucat, 2003) further argues that:

*Through our narrow view of the discipline of chemistry, we have already lost the opportunity to embrace some of the emerging fields of science within Chemistry. It is time to be more aggressive in convincing students in related (science) disciplines of the need to study more chemistry.*

(p.4)

Put more simply, this means that Chemistry 1 needs to be taught more as an ‘enabling’ science rather than as ‘pure’ chemistry. Bucat concludes:

*Perhaps the most important ingredient of an achieving student is motivation. And perhaps the most important ingredient to being motivated is knowing why it is important to know what you are being taught.*

(p.4)

A consistent theme of the discussions with Heads of Chemistry Departments was how to motivate students to become interested in chemistry. The answer is inherent in the ‘way’ that chemistry is taught at the Year 1 level. Put more concisely, the traditional ways of teaching chemistry, so well entrenched in chemistry teaching philosophy, are not motivating 21st century science students.

The crisis in tertiary chemistry education, although recognised by the profession, was not widely recognized by Governments or in the public arena. Cross and Hill (2001), (Appendix 1) highlighted this:

*Chemistry is too often seen as a prerequisite for another career rather than a legitimate career in itself.*

and:

*If Australia is to play a full partnership role in the development of a global technological society, it is essential that chemistry contributes fully to national life. Chemistry is life-long learning experience. It must be understood that advances in biotechnology, environmental science, forensic science and medicine all depend on advances in chemistry. Chemical research has to be seen as vital to the national need.*

(p.13)
The need for urgent reform of tertiary chemistry education was further discussed at national and international chemical education conferences (Hill and Cross, 2001 to 2003). (These papers are included in Appendix 4). The aim of these conference presentations was to reveal the key message derived from the interviews with Heads of Chemistry Departments undertaken in 1999 that the demise of chemistry in Australia was a multi-faceted problem. It was apparent from declining numbers of secondary school students electing to study chemistry at the senior level, declining numbers of tertiary science students electing chemistry as a major in the BSc course, a declining chemical industry in Australia and a concomitant decrease in employment opportunities for chemistry graduates, a pessimistic public image of ‘chemistry’ accentuated by the media and, most significantly, progressively declining government financial support for education generally and tertiary education in particular, coupled with declining financial support for scientific research, particularly, fundamental research.

A more pungent message aimed directly at the Federal Government was published as a media release by the Royal Australian Chemical Institute (RACI) in 2001, (Appendix 1). This was referred to in Chapter 1 as one of the major motivations for the present project. Under the title ‘Rebuilding the Enabling Sciences- Reclaiming the key to unlock the Nation’s potential’, it defined the demise of chemistry thus:

If the current university (science) staff losses continues, there will be no chemistry, physics, mathematics and engineering education to support technological innovation beyond 2020 and if the current rate of secondary school participation in the enabling sciences continues, these sciences will disappear from the curriculum by 2020. (p.3)

It can be concluded that the chemical education system in Australia is in crisis because chemistry in our universities is progressively becoming ‘self-eliminating’. The interviews of this research revealed that unless some urgent steps are taken to address and reverse the trends identified by the RACI statement, the future of ‘chemistry’ as an ‘enabling science’ in Australia is seriously threatened (Hill and Cross, 2002).
In support of the decline of chemical education in Australia, a recent article in ‘Chemistry World’, Price (2005), has identified the central dilemma:

It is a great irony that in a time when chemistry and the use of chemical principles are to dominate human activities as never before that chemical education (in Australia) is sliding into obscurity. (p.1)

and:

The demise of chemistry education seems to be a global problem but the symptoms have regional variations. In the UK, chemistry departments are closing. In Australia, there has been a rapid decline in the size of chemistry departments, with the number of staff, both academic and technical per department dropping precipitously. Does this mean that the importance of chemistry is decreasing? (p.1)

Price argues that the importance of chemistry is self-evident – but perhaps the root of the problem is the paradox that chemistry is so all-encompassing that it has developed an identity problem. This paradox is chemistry’s strength because it shows that chemistry is an enabling science that underpins all sciences, medicine and industry. But it is also a weakness because nebulous definitions lead to hazy perception of career opportunities. The future of chemical education in Australia can only be guaranteed if we can more clearly define chemistry. (p.1)

In the context of the present research, this conclusion is most relevant since to make chemistry more ‘attractive’ as a course of study, it is necessary to simplify its content, to relate its principles to everyday experience and to identify exciting career opportunities for trained chemists.

Prior to discussing other initiatives in ‘local’ chemical education, it is appropriate to appreciate that some research has been conducted on the ‘first year (University) experience, in the context of ‘sharing the first year experience’ (Champion et al., 1998), ‘easing the transition’ and devising strategies to help first year learners (Ferranty and Lynch, 2001) and ‘using study guides to develop communication skills (James and Tanian, 2001). These studies all concede that there
are special problems associated with teaching and learning at the tertiary Year 1 level arising primarily from a wide diversity of educational backgrounds of Year 1 students. This is a well-recognized phenomenon with respect to Year 1 science students and is one of many drivers predating change of teaching style at this level.

In this context, The Educational Services and Teaching Resources Unit of Murdoch University has compiled a very useful manual ‘Teaching University Students Chemistry – Approaches Your Colleagues have tried’ (Barrett, 1991). This is a comprehensive summary of journal articles on teaching and learning in tertiary chemistry over the period 1975 to 1990. The manual essentially is a communication medium for teachers of tertiary chemistry and in part addresses one of the key problems identified by Bucat (2001) that Year 1 chemistry teachers have little practical experience of education in chemistry.

With respect to the learning and teaching aspects of chemistry, Dearn (1999) argues that ‘(Chemistry) is dull to learn (and) dull to teach’ because students are not ‘engaging with science through discussion and collaboration’. Dearn believes that attitudes of science academics need to change, particularly those involved in teaching first year science courses since many believe that:

> The high attrition rate of students in science courses is typically rationalized by science faculty by saying that only a small proportion of students are capable of undertaking science because of its intellectual demands. (p.23)

Dearn concludes that:

> If effective learning involves students engaging with other students and staff in discussion and collaboration, then the spaces we create must not only allow that to happen but actively encourage it. This reminds me of that lovely definition of teaching which says that teaching should be leading students into situations they can only escape from by thinking. (p.26)

Here is a clear indication that teaching methodologies in Chemistry 1 must change.

Further, Borchardt, 2001, examines why there is widespread disinterest in the ‘hard sciences’ such as chemistry as compared with increased interest in the ‘soft sciences’ such as psychology. Borchardt argues that such disinterest arises from teaching of the hard sciences in abstract terms rather than stressing the relevance of chemistry to the students’ experience. It is proposed that students pursuing other
Science disciplines need to be taught chemistry so that they can identify chemical problems in their chosen discipline and be able to pursue reasonable solutions using the scientific method. This philosophy is in harmony with that of Bucat, 2001 who suggests that ‘chemists need to shift the goal posts of their discipline’ so as to embrace and indicate the importance of chemistry in aligned scientific disciplines. Baker (2005) believes that this can be achieved by greater emphasis being placed upon laboratory chemistry whereby it can be shown that in order to be a professional chemist, there are certain craft (practical) skills that have to be mastered and in the laboratory, chemical concepts can be reinforced by hands-on experience. Further, laboratory chemistry experience is a preface to and essential training for laboratory chemistry work in industry.

In a related article titled ‘Experiencing Chemistry’ (Youl, 2001) argues that ‘industry placements’ during the senior school levels can greatly assist students to better appreciate chemistry at a time when they are critically considering the merits of a science-based career. Numerous case studies indicate how such placements help students to understand not only the basics of chemistry but how chemistry relates to the real world and how chemistry can solve real problems and contribute positively to society. The interviews with Heads of Chemistry Departments indicated a lack of interaction between academic chemistry and industrial chemistry and it can be concluded that ‘industrial placements’ could considerably enhance tertiary teaching and learning of chemistry.

It is recognized that a major conceptual difficulty which students have at the Chemistry 1 level is an understanding of chemistry at the molecular level or more specifically visualizing chemistry at the micro-level. This distinction characterizes chemistry as a ‘molecular science’ and differentiates it from the more qualitative sciences such as biology. In an article titled ‘Chemistry by Computer (Smith, 2001) argues that:

The ability to accurately simulate molecular structure, molecular interactions and chemical reactions is a crucial part of progress in modern science. Without this ability, for example, we are unable to model or predict the evolution of pollutants in metropolitan atmospheres, the concentrations of ozone and its predatory species in the stratosphere, the efficiency and the emissions of combustion processes, the structure and functional properties of
proteins, enzymes and other biopolymers or the properties of the materials which underpin new technologies.  

(p.8)

Smith further argues that ‘chemical education in the information age’ must be inclusive of the principles of computational chemistry, chemometrics and the specification of chemical identity through nomenclature and database storage. It is therefore apparent that Chemistry 1 students need to be aware of these advanced methodologies in the context of making chemistry relevant, exciting and challenging.

The interviews with Heads of Chemistry Departments indicated that one of many challenges in teaching Chemistry 1 is to present chemistry as an ‘exciting’ science. In this context, Savage (2000) argues:

While it is true that industry still appreciates the value of chemistry our political masters, granting bodies and student population are more captivated by the ‘sexy’ new disciplines. To add to the insult, these neophyte disciplines have actually pinched some of the best bits of chemistry and called them their own.  

(p.3)

Savage concludes:

There is not much point in fighting this trend. What we need to do is demonstrate to the world that chemistry not only underpins the exciting new areas (the sexy sciences) but that it is a highly creative area in its own right.  

(p.3)

The interviews revealed that somewhat reluctantly, Heads of Chemistry Departments and Chemistry 1 lecturers are recognizing that the way forward is not to sub-divide chemistry into the traditional sub-disciplines of ‘inorganic’, ‘organic’ and ‘physical’ since ‘modern’ chemistry is embedded into the broader disciplines such as biochemistry, process chemistry and materials science – to name just a few. Savage argues:

Name changes and getting the language right are only one step. Equally important is getting the message across that chemistry is exciting, innovative, creative and challenging. We (chemists) all need to convey that excitement to students and government, who are our human and financial lifeblood, respectively.  

(p.3)
Savage concludes with a poignant call to action:

*The human genome project will only illuminate the targets to defeat disease-someone still has to make and fire the magic bullet! (p.3)*

That ‘someone’ is surely a chemist who can ‘make’ and ‘direct’ the magic molecule(s) in question.

A long-term advocate of ‘committing chemistry to a public place’ has been Selinger, whose book ‘Chemistry in the Market Place’, now in its fifth edition (1998) is internationally recognised as the ‘master work’ in this field. In a later article, Selinger (2003) recognizes the pivotal dilemma:

*The scientist is not ‘experienced’ directly by the community, and the media’s depictions tend to emphasise the extremes of science and technology.*

and:  

*‘Many of the conflicts concerning science in the public domain result not so much from a lack of understanding of science by the public but from a lack of understanding of the public by scientists’. (p.240)*

In a further article, Selinger (2003) discusses the ‘quest of science for black and white in a grey society’ and argues that the public tends to cling to ‘stereotyping’ in its attitude to ‘science’:

*Quite a large proportion (but not all) opposition to genetically modified food has much more in common with the defense of the likes of organic, vegetarian, halal and kosher foods. The link is with a belief system.* (p.3)

It is appropriate to conclude here that a ‘science for all’ educational philosophy has the potential to scientifically inform the ‘belief system’ and, as will be shown in Chapters 6 and 7, is one important component of Lawton’s systems for curriculum design.

An article titled ‘Medicines: from magic to macromolecules’ (Jurgen et al., 2003) emphasizes that medicinal science and drug technology are branches of chemistry and not new sciences. It is concluded that convergence of chemistry and pharmacology leads to the emerging discipline of pharmagenomics and it is this type of linkage between chemistry and other traditional sciences which needs to be recognized in terms of redefining the boundaries of chemistry. Changing the public
image of science and chemistry in particular, is a profound and continuing educational process which relies not only on a change of public perception of science but also on a change of the scientists’ perception of science.

The interviews of this research engaging with Heads of Chemistry Departments indicated a widespread lack of communication between academic chemistry departments and the chemical industry. Dunn et al., 2000 have argued that:

Students in tertiary education are effectively cocooned from the real world. There is a need for a unit of their course to link the chemistry they have already learned to the situations which they are likely to encounter upon gaining employment. (p.18)

A unit titled ‘Chemistry & Technology’ has been included in the final year of the B.Applied Chemistry degree (Curtin University of Technology) which offers industry placement in the areas of consumer chemistry, environmental chemistry, industrial electrochemistry, mineral chemistry and industrial organic chemistry. Subsequent to this inclusion, the B.Appl.Chem. at Curtin is recognized as both a professional and technical qualification. However, there are limited opportunities to introduce a ‘chemical industry placement’ component into the already crowded Chemistry 1 curriculum – unless the curriculum is revised and priorities changed.

The interviews of this research revealed that it is widely recognized that the chemical industry in Australia has been in decline over at least the last two decades and that this is a contributing factor to the overall decline of job opportunities for graduate chemists. However, consistent with that decline, the Australian chemical industry has undergone major reform and restructuring to address its niche global market share (Van Santen, 1998) and development plans have been announced (Abrahams, 2002) (Blackman, 2002). With respect to the ‘Pharmaceuticals Industry Action Agenda’, Blackman states:

The global (pharmaceuticals) industry is changing. No longer are the large vertically integrated multinationals seeking to do everything in-house. Rather, they are seeking industry and academic partners who can work in a range of disciplines from custom drug design and synthesis to drug analysis through early to late stage clinical trials to commercial supply of active ingredients. All of these activities require highly skilled and commercially savvy chemists. (p.18)
The central message here is that the Chemistry 1 course has to include reference to the commercial significance of chemicals in conjunction with their composition, structure and reactivity if ‘skilled commercially savvy chemists’ are to be produced.

It is gradually becoming a ‘fact of life’ that the ‘science of the future’ is ‘sustainable science’ and ‘sustainable chemistry’ translates to ‘Green Chemistry’. Green Chemistry is changing the image of the chemical industry and is perhaps the long-awaited salvation force to change the public image of chemistry. In these contexts, the pioneering Centre for Green Chemistry (CGC) based at Monash University is leading the way in Australia (Scott et al., 2001). Green Chemistry represents an approach to chemical synthesis and to the manufacture of new chemical products that are ‘benign by design’ and are thus ‘environmentally friendly’. The CGC argues:

*With costs of waste management and disposal escalating, green chemistry makes sound business sense and provides opportunities for cooperative development among chemical companies, academia and government agencies. Thus, green chemistry is an ideal vehicle for allowing the Australian chemical industry to address the issues of globalization as well as safety and the environment.*

(p.10)

It has been argued (Kenward, 2004) that chemical industries, large and small, must demonstrate the value they bring to society and persuade everyone that they operate responsibly. Chemical industries must address ‘sustainable development’ which adds to the economic and social aspects of doing business. Thus, it is apparent that the Fensham ‘science for all’ ethic incorporates a commitment to ‘sustainable science for all’.

It is recognized that the key message of ‘green sustainable chemistry’ must be included in chemical education at all levels. The challenge is that understanding and applying green chemistry requires a detailed understanding of basic chemical principles particularly those of synthetic chemistry. In a typical Chemistry 1 course, synthetic chemistry is largely confined to the organic chemistry component coupled with one or two organic laboratory exercises. Hence there is scope for adapting the synthetic chemistry to have a green chemistry emphasis and focus. At least the central message of ‘green sustainable chemistry’ must be included in the Chemistry 1 course.
No discussion of chemical education developments in Australia would be complete without reference to the over-arching support initiatives of the Royal Australian Chemical Institute (RACI). Unfortunately, as will be discussed in Chapter 4, these are not as intensive and extensive as those of comparable professional societies in the US and UK but nonetheless are of relevance to the present research and the present debate. The major chemical education focus of the RACI is the Division of Chemical Education which hosts an annual national chemical education conference and publishes the *Australian Journal of Education in Chemistry*. A further major initiative is the annual Professors and Heads of Departments (PHODS) meeting which largely establishes and modifies policy options for chemistry in Australian Universities (White, 2002). The Institute is also the chief accreditation body for tertiary chemistry courses in Australian Universities. In terms of schools outreach initiatives, the RACI organizes National Chemistry Week which includes the ‘Chemists in Schools Program’ aimed specifically at exposing upper primary students to the wonders of chemistry. For secondary students, there is the annual Hartung Youth Lecture which is delivered in many centres and is lavishly illustrated with captivating demonstrations. Also, the RACI distributes widely to schools free on request, a poster series on Nobel Laureates and ‘Not all Chemists wear White Coats’. The RACI has also (recently) offered membership to secondary school (chemistry) teachers and the RACI National Chemical Education Conference has sessions devoted to the teaching of school chemistry.

It is relevant to note here that although the RACI continues to monitor and accredit chemistry courses in Australian Universities, it does not comment on the content thereof except in terms of ensuring that the requisite chemistry content is fulfilled. The interviews with Heads of Chemistry Departments revealed that the widespread view of academic chemists confirmed that in terms of chemistry course content, the present role of the RACI was entirely appropriate and should not be extended to appraise course content. They believe that it is entirely the prerogative of academic chemistry staff to prescribe the content of tertiary chemistry curricula.

The RACI has been effective in defining policy options for chemistry in Australian Universities particularly in terms of the current changes in the Higher Education funding structure as first announced in ‘Higher Education at the Crossroads’ (DEST, 2001). These changes present even greater challenges than previously to a sustainable level of chemical teaching and research in Australian
Universities at international standard. The 2001 PHODS meeting was significant in drafting the RACI ‘Enabling Sciences Initiative’ (Appendix 1) which was aimed at warning the Federal Government that the ‘enabling sciences’ are asymptotically declining into insignificance since the Universities are unable to sustain a creditable supply of graduate scientists, in particular, chemists, physicists and mathematicians.

Two additional RACI policies indirectly affect chemistry teaching at the tertiary level, as given in the ‘Policy options for chemistry in Australian universities: A discussion document’ (White, 2002):

To ensure undergraduate and graduate student training at the best international levels, cooperation should be facilitated between universities in the same city and between country and city universities in course work and research infrastructure provision. (p.24)

And:

The Federal Government should encourage practical regional alliances between tertiary educational institutions, promoting complementary teaching and research strengths. (p.24)

The latter has already happened in Victoria with the formation of the Victorian Institute of Chemical Sciences (VICS) – an alliance between the Chemistry Schools of Melbourne and Monash Universities and the Department of Applied Chemistry of RMIT University formed by a foundation grant from the Victorian State Government as part of its Science, Technology and Innovation (STI) Initiative (2002) (Adams et al, 2002). One of the four themes of VICS is to provide ‘chemistry education and outreach’ and to establish the Institute on a sound commercial base which will ensure its sustainability and growth.

The 2004 PHODS meeting had the theme ‘Wither Chemistry – Chemistry Withers? – Where to for Chemistry in the Tertiary Sector’ and again addressed the central issue of the decline of the enabling sciences and, in particular, the decline of interest in chemistry at the secondary-tertiary interface. In heeding the advice of Lambert (2001):

One thing we might think of doing to ensure a strong supply of expert chemists is to take every opportunity to describe the richness of our science and convince these bright young people that the science of chemistry is a complex creature of growing proportions. (p.3)
A steering committee was established to undertake a research project titled ‘The Future of Chemistry’. The full report of this committee is due in mid-2005 and will focus on the supply, quality and demand of graduate and post-graduate chemists. The essential conclusions of this report are summarised in Chapter 9. This initiative has probably come ‘too late’ to nullify the central crisis identified by this research but at least it will further quantify its status.

The RACI also has a major role in linking chemical education in the Asia-Pacific region as documented by Hollingworth (2001) and it does this through its membership of the Federation of Asian Chemical Societies (FACS) and its sponsorship of ‘Pacificchem’, a chemistry conference jointly sponsored by ‘pacific-rim’ chemical societies and held every five years in Hawaii, includes a number of symposia on chemical education and these will be discussed in Chapter 4.

A valuable information resource on research developments in learning and teaching of science is the annual Australasian Science Education Research Association (ASERA) Conference and on leading recent developments in the learning and teaching of chemistry, the annual RACI National Chemical Education Conference is the premier forum of its type in Australia.

The 2003 ASERA Conference emphasized the need to include sociological, historical and philosophical elements in the teaching of science both in schools and universities with the aim of embracing the Fensham ‘science for all’ vision in science curricula at all levels. Presented papers addressing this theme included ‘Considering social responsibility and the science curriculum’ (Kearney, 2003) which considered the impact of ‘Science, Technology and Society’ (STS) on school science curricula and the extent to which the ‘Science for All’ approach has been achieved. A further paper titled ‘The case for a philosophy of chemistry education: how should we teach atoms and molecules?’ (Harrison, 2003) addressed ‘knowledge growth’ in chemistry and argues that in school science curricula, the concept of atoms and molecules is axiomatic and proposes that this concept needs to be linked with the history and epistemology of chemistry for a mature understanding of ‘particle ontology’. Another paper titled ‘A question of style: how Queensland teachers are enacting a ‘science for all’ curriculum’ (Hanrahan, 2003), explores the ways in which science teachers go about engaging students physically, emotionally and intellectually in science. A further relevant paper titled ‘A socio-cultural view of learning science and technology at university: the contribution of a work placement’ (Eames, 2003) promotes a
cooperative education program that combines periods of workplace learning with institutional learning and discusses the results of interviews with students who had undertaken this socio-cultural learning exercise. Little research is being conducted in Australia on ‘chemistry learning’ and Bucat and his research group at the University of Western Australia is the leading force in this area. A paper entitled ‘Can I see what you see?’ (Bucat et al., 2003) explored the difficulties which students experience visualizing and understanding molecular structure and how students translate from one type of representation to another. A keynote paper titled ‘An overview of chemical education: towards research-based practice’ (Treagust, 2003) argues that the current global revision of the structure, content and provision of chemical curricula at all educational levels will only be effective if it is based on the collective research into the problems that are currently faced together with evaluated outcomes of attempts to address them. This is in effect the philosophy on which the present research project is based.

The RACI Chemical Education Division Conference has the primary goal of bringing together all those interested in the teaching of chemistry from the school, university and industry sectors. A keynote paper presented at the 2002 conference titled ‘Chemistry STILL IS the central science’ (Denny, 2002) proposes that -

(a)mong scientists it is intuitively obvious that chemistry is the central science but it has been ‘buried’ by the ‘new’ sciences which have derived therefrom. In a sense, chemistry has been too successful! Students want to study the new ‘sexy’ sciences such as drug development but do not realize that they need a qualification in chemistry. Chemistry has spawned a plethora of new sciences, which significantly do not include ‘chemistry’ in the title, eg Biotechnology, Environmental Pollution Control. Also there is a perception that chemistry is a ‘mature science’ with no challenges left. The exact opposite is true and perhaps this is the central challenge of chemical education in the 21st century. (p.16)

Denny continues:

Science is rapidly transcending to the molecular level and since chemistry is a molecular science it must occupy a central position in the sciences of today. It has not passed its ‘use by’ date. (p.16)
In a further keynote presentation titled ‘Looking beyond the burette’ (Oppenheim, 2002), a perspective on chemical education is given by an industrial chemist. Oppenheim argues that:

The image of chemistry is that of a ‘burette’. The challenge of chemical education is to relate this image to ‘life’. (p.17)

Oppenheim further argues that chemistry is controlled by chemical events and that life is enriched and made more enjoyable by chemistry and that chemistry is not in decline, it is still essential to everyday life. This is the central message that teachers of chemistry need to promote. Oppenheim continues:

We, as chemical educators, must sow the seed of chemical knowledge as early as possible. We need to start in primary school and capitalize on the fact that children are always curious and are eager to ask ‘why’. Chemistry can explain the ‘why’. The (chemical knowledge) seed emerges in secondary school. All stakeholders have to protect and restore the seed as it develops. At the tertiary level, the seed needs to be focused, supported and directed but most of all the developed seed needs to be valued and nurtured. (p.17)

Oppenheim then addresses the dilemma of a declining interest in chemistry in an environment which requires chemistry for its sustainability. He claims that chemical education is failing to excite students to study chemistry at all levels. Oppenheim argues that tertiary chemistry courses tend to be research focused to the detriment of teaching, present interesting but irrelevant material, and that the teachers have no experience of chemistry in the real world. As a result, students are disenchanted and are ill-prepared for the (chemical industry) workforce. Oppenheim argues that the chemical industry needs chemically aware young enthusiastic employees who understand chemical ideas without a detailed chemical knowledge. [It is relevant to note that traditionally, industrial chemists have had very little input into the structure of chemistry curricula at both the secondary and tertiary levels and this is perhaps the reason why students have difficulty relating the ‘theoretical’ to the ‘practical’ chemical world.]

Three additional papers focus on the nexus between learning and teaching of chemistry. A paper titled ‘Rethinking the teaching of science – research into student learning’ (Dearn, 2002) proposes that:
Science should be taught in terms of providing a ‘model of the world’. (p.20)

Dearn continues to argue that learning is an interactive process between teacher and student and discusses the components of ‘the knowledge engine’. He concludes that ‘assessment’ is the main driver of ‘learning’. In a related paper titled ‘First Year Chemistry assessment – time for a reassessment’ (Hollingworth, 2002), it is argued that ‘learning is equivalent to knowledge transmission’ and that ‘learning should be activity based and not context based’ which is a characteristic of ‘problem based learning’. PBL has only recently been considered as a new paradigm of teaching in the Chemistry 1 course. Hollingworth concludes:

*We must expose our students to problems requiring higher order skills with less reliance placed on traditional exams.* (p.21)

In a further paper titled ‘The role of sub-microscopic and symbolic representations in chemical explanations’ (Treagust, 2002), it is argued that:

*Good teaching converts knowing ‘how’ to knowing ‘why’ and is the foundation of building a knowledge network.* (p.74)

Treagust further develops this theme with a discussion of a knowledge network containing three elements ‘symbolic’, ‘macroscopic’ and ‘sub-microscopic’ related to ‘model based learning’ of chemistry. It is concluded that the adopted model has to be simple but accurately represent the concept. The challenge is in the choice of simple, representative models.

The 2004 RACI Chemical Education National Conference plenary was delivered by the internationally renowned Professor of Physical Chemistry at Oxford University, Peter Atkins. He addressed the assembly on ‘Modern trends in Chemical Education’. He commenced by considering the reasons for the decline in interest in chemistry and its demise in terms of its quantitative character:

*Students are overwhelmed by the intricacy of chemistry – they are not trained in intricacy appreciation. Students fear the abstraction of chemistry and the difficulty of visualizing atoms molecules, entropy, energy etc. Students find chemistry ‘hard’ and softer option courses always available even in science.* (p.62)

Atkins also recognizes that chemistry students come from a variety of backgrounds and competency levels and chemistry has a negative public image that of ‘the great polluter – the nasty science’. Thus, a rebuilding process is called for and teachers of
chemistry need to think positively and constructively and convert ‘difficulty’ into ‘opportunity’. The image of chemistry needs to be changed from a ‘nasty science’ to a ‘high tech science’, an environmentally caring science, one which advances everyday life: ‘Chemistry is the solution not the cause’. Atkins continued to discuss the role of multimedia in the teaching of chemistry – its unparalleled ability to visually relate the macro world to the micro world of atoms and molecules but with the simultaneous ability of destroying ‘imagination’ which is the life blood of scientists. Atkins concluded that multimedia is not the answer to the problem of restoring interest in chemistry since so much is portrayed visually there is no need for imagination on the part of the student and no real sense of achievement in learning effectively. Some key advice was given on chemistry curricula reform. Atkins believes that chemistry is inherently composed of a small number of ‘core ideas’ which he calls the ‘nuts and bolts’ of chemistry which are more generally referred to as ‘basic chemistry’. Atkins believes that these core ideas must be ‘taught’ so as to reveal the ‘beauty of chemistry’ and in such a way as to ‘reduce the fear of the abstract’ and to show that the core of chemistry is not so intricate in detail or scope but conversely has vast ramifications. Atkins also believes that the ‘core ideas’ are linked directly to ‘key techniques’ which ‘quantify’ these ideas and remove their abstract character. This philosophy represents a new paradigm in teaching Chemistry 1 and these ideas are discussed in detail in Chapters 6, 7 and 8, since they are a key ingredient of the new Chemistry 1 curriculum framework generated by this present research.

In a review paper titled ‘Parallel Universes: Education Research and Chemistry Teaching’ (Coll and Taylor, 2003), chemistry teaching is linked to new ideas about how students learn thus strengthening the interaction between educational research and teaching. A case is made for teaching chemistry in accordance with Wheatley’s (1991) theory of constructivism in which science is seen as a body of knowledge which can be transmitted to the learner duly recognizing prior knowledge of the students and the attempts of the teacher to foster active learning. An ‘action research’ approach to the teaching and learning of chemical bonding is proposed following an ‘action research spiral’ plan. A group of teachers in collaboration with an education researcher identifies a specific cognitive problem such as ‘chemical bonding’ and plan how this might be addressed through different pedagogies including multimedia. This agreed approach would then be implemented, reflected upon and revised before subsequent implementations. The 1999 interviews with
Heads of Chemistry Departments revealed a paucity of chemical educational influence on the Chemistry 1 course and hence there is a need for interaction between educational researchers and Chemistry 1 lecturers and this identified present deficiency is further addressed in Chapter 6.

It has long been recognized in universities and particularly in departments of chemistry that the essential difference between teaching at the secondary level and teaching at the tertiary level is that the latter is ‘informed by research’. In a paper entitled ‘Periodic learning’ (Forrest, 1999) it is argued that:

A good teacher needs infectious enthusiasm, willingness to try new things, a love of working with students and of course an excellent command of their subject. Unfortunately, these talents have been undervalued in many universities over the years.

Historically, climbing the promotional ladder has been heavily dependent on research performance which has effectively acted as a disincentive for academics to focus too much of their energy on becoming engaging and skilled educators. (p.17)

The central message conveyed here is that academics need to find a balance between teaching and research. With respect to chemistry, it is certainly recognized that active researchers are able to convey to students the ‘cutting edge’ excitement of chemistry more effectively than passive researchers. However, an increasing trend in chemistry departments is for staff to take out ‘teaching only’ contracts and it is unfortunate that many of these are either directly or indirectly involved in teaching Chemistry 1. It does not automatically follow that those on such contracts are ‘good’ teachers.

In a paper titled ‘Small group learning in first year chemistry: Does it work?’ (Munk and George, 2003), the effectiveness of small group project work as a teaching technique in a large first year chemistry group is examined. The aim of the project work was to enhance student motivation and learning in chemistry as well as to develop a problem solving approach to chemistry, encourage group learning and develop communication skills. The outcomes of the study were that students found the content of the projects interesting and that the projects made it easier to understand some chemical concepts covered in the lectures. Further, generic skills such as ‘group work/peer interaction’, ‘communication/presentation’, ‘problem solving’ and ‘critical analysis’ were some key drivers to the success of ‘small group
learning’. Certainly these skills are not inherent in the conventional long-term presentation of Chemistry 1 and this study shows the importance of creating an interactive learning environment at this level.

Lim, (2003) has investigated ‘The ability of beginning university chemistry students to use information and communication technology (ICT) in their learning’. This study found that whereas the general level of ICT skills among such Year 1 students continues to improve, there are minor deficiencies in the use of word processors, the world-wide-web and in meta-cognitive skills. There are major deficiencies in the use of spreadsheets, library databases, presentation software and computer conferencing with additional deficiencies in the use of relational databases. New teaching methodologies rely very heavily on students being ‘computer literate’ and this study shows that commencing Year 1 chemistry students require a parallel course in computer skills.

Learning, as described by Vosniadou (1994), can be considered as the addition of new information to existing frameworks of ideas and the restructuring of these conceptual frameworks. Problem solving is an integral component of any undergraduate chemistry program. In a paper titled ‘Problem solving in inorganic chemistry - The use of Spider Diagrams’ (Murphy and Hathaway, 2002), it is shown how problem solving in chemistry can be presented in graphic form which is different from the idea of a ‘concept map’. Spider Diagrams can be considered as a form of ‘centre-outward’ concept consistent with a central question surrounded by a sequence of circular answers consistent with the central working method of the problem. This approach can easily be used in the Chemistry 1 course – particularly with respect to problem solving in physical chemistry.

A most innovative new learning methodology related to practical physical chemistry is the APCELL project (Australian Physical Chemistry Enhanced Laboratory Learning Project) introduced in 2000 (Barrie et al., 2001). This project was established to address the problem of declining student enrolments in chemistry and particularly, the declining interest in physical chemistry. The project pooled the resources of over 30 Australian universities to establish a protocol for developing and assuring the quality of laboratory teaching experiments in physical chemistry. This project has recently been extended to all areas of chemistry and has been renamed ‘The ACELL Project’. Using a ‘research-led teaching’ approach similar to that encouraged by Coll and Taylor (2003), an ‘educational template’ was developed to
ensure that contributions to the project are strongly learner focused. Essentially the APCELL/ACELL project brings together academics from most Australian Universities to enhance the quality of laboratory teaching in physical chemistry. In particular, the project produces a data base of student-centred, validated laboratory experiments in chemistry at the Year 1 level using the research-led teaching (RLT) pedagogy. The project has now been operating for four years and feedback has shown that the RLT approach to laboratory teaching enhances motivation in students for enjoying laboratory practical work and provides them with an enriched learning experience.

In a very provocative paper titled ‘Towards a flexible learning and teaching environment for Level 1 Chemistry’ (Crisp, 1999), it is argued that: New technologies, external expectations and the dynamic nature of chemistry all shape the learning and teaching environments of our universities. (p.6)

A new curriculum is proposed for Chemistry 1 whereby the teaching of the content is innovative and imaginative rather than repetitive. The aims for Level 1 Chemistry are also redefined thus:

To encourage critical thinking, to enhance problem-solving ability, to gain an appreciation of scientific methodology, to encourage professionalism, to provide a basis for further study in chemistry and other sciences and to provide students with a career path in chemistry or a science-related area. (p.7)

This set of aims is to address the current perception that - (s)ociety expects graduates that are critical thinkers and not simply laboratory machines. (p.7)

The subject content of the new curriculum is more contextual than previous (traditional) chemistry curricula and follows the school-leaving certificate framework with extensive interrelation of sections and frequent revision of key concepts. Isolated facts or information that is not used elsewhere in the course is omitted and the overall outcome is to produce a Chemistry 1 curriculum that is more cohesive and seamless. Crisp believes that:

Our experience has been that with proper planning, genuine syllabus reviews and a reflective use of computer technologies, staff can provide a more flexible learning and teaching
This approach is the most radical ‘change’ that has occurred with respect to the structure of the Chemistry 1 course in at least a decade of debate on its content and this framework will be discussed in more detail in Chapter 6.

It is apparent from this brief review of developments in tertiary chemistry education that a variety of attempts have been made to address the central problem of declining interest in chemistry by commencing tertiary science students. However, although these attempts have been seriously initiated with the best of intentions, the overall outcome is that the central problem still pertains and it was this conclusion that was a major impetus for undertaking the present research project.

3.6 CONCLUSION

This review of chemical education developments at the primary, secondary and tertiary levels has revealed that current chemistry curricula fail, in general terms, to address the recognized crisis related to the declining status of chemistry in Australia. Thus it is apparent that reform of chemistry courses at all levels is required. Although the present research is focused on a restructure of the tertiary Chemistry 1 course, this review has identified a number of key factors which inherently drive such reforms. Perhaps the most significant of these is the issue of ‘scientific literacy’. It is apparent that this is not achieved by school-leavers having completed Years 11 and 12 chemistry or by tertiary students having completed Chemistry 1. Fundamentally, the senior school chemistry courses and the Chemistry 1 course fail to deliver the illusive outcome of ‘scientific citizenship’ based on the formula: Knowledge + Application + Society Interaction = Scientific Literacy. Society needs to be able to make judgements on the basis of scientific evidence and not on emotional and uninformed opinions. A lack of scientific literacy at the end of schooling may translate to a lack of interest in science at the tertiary level and a perception of science being ‘difficult’ and not relating to the real world.

A further driver for reform is the need for a streamlined sociological emphasis in chemistry curricula, particularly at the Year 1 tertiary level. This present deficiency correlates with a lack of scientific literacy and a lack of motivation towards studying chemistry or choosing chemistry as a career path. It is a crucial driver for reform.
Other key factors driving reform which have been revealed by this review are that the Chemistry 1 fails to reveal the significance of chemistry as an ‘enabling science’, fails to reveal the connectivity of chemistry to other sciences, fails to include reference to the history and philosophy of chemistry, fails to reveal chemistry as an embracing science, fails to emphasize the culture and richness of chemistry and, most importantly, it fails to raise the public perception of chemistry. Overall, the Chemistry 1 course fails to excite students in the wonderful science of chemistry due to a propensity of traditional lecturing styles being retained together with a lack of interactive learning opportunities. Thus, the present Chemistry 1 course widens the nexus between teaching and learning and, in Australia at least, there is insufficient educational research in chemical education to address this prominent factor.

Further, the 1999 interviews with Heads of Chemistry Departments revealed that in broad terms, ‘blame’ for the problems with Chemistry 1 is levied on ‘external factors’ such as ‘declining departmental budgets’, ‘declining staff compliments’, ‘OH&S constraints’, ‘ageing infrastructure’ whereas this review of chemical educational developments at the tertiary level, tend to show that the central problem relates to ‘internal factors’ and particularly to the structure of the Chemistry 1 course and the need for urgent reform based on a comprehensive educational research philosophy and this is the key driver for the present project which is fully developed and exploited in Chapters 5, 6 and 7. Further, the theoretical statement of this thesis, which is developed in Chapter 7, builds on the ideas of Atkins and Fensham in terms of ‘chemistry being constructed of simple ideas’ and ‘chemistry has a social responsibility’.

Finally, this literature review of chemical educational developments in the secondary school and university sectors has revealed the differences between the former and the latter and the paucity of educational research into tertiary chemical education which gives further endorsement of the present research.
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CHAPTER 4

INTERNATIONAL REFORMS IN CHEMICAL EDUCATION

4.1 INTRODUCTION

A concise overview of significant chemical education developments in Australia was given in Chapter 3 and, in particular, the chemical education developments that have impacted on the tertiary Chemistry 1 course in Australian Universities. It is now appropriate to overview the international developments in chemical education at all levels, in particular, the developments that are based on educational research related to the current aims and objectives of science education, particularly the philosophical, historical and sociological emphases.

4.1.1 Purpose

The purpose of this chapter is to identify the issues driving reform of chemical education internationally which are of particular relevance to the reform of the tertiary Chemistry 1 course, both internationally and in Australia. A comparison of chemical education developments internationally with those in Australia will be made in order to assess the impact of chemical educational research on the declining status of chemistry worldwide.

4.1.2 Scope

Particular emphasis is focused on chemical education developments in the UK, USA and Europe which relate to the secondary and tertiary levels. Further, the influence of professional societies such as the American Chemical Society (ACS), the Royal Society of Chemistry (RSC) and the Federation of European Chemical Societies (FECS) on chemical education is assessed in the context of support for the teaching of chemistry and leadership in development and reform of chemistry courses, particularly at the tertiary level. The association of the international chemical industry with chemical education at the secondary and tertiary levels is also assessed.
4.1.3 Limitations

In view of the vast international chemical education literature, limitations on the review thereof are necessary. The first limitation was to restrict the review to publications published over the last fifteen years and then to focus on developments of chemical education in the secondary and tertiary education sectors. A related review of the international status of chemistry was also undertaken since it was necessary to find out whether the demise of chemistry in Australia was a unique phenomenon or whether this had global significance.

4.1.4 Outcomes

The overview of international chemical education developments is focused on an identification of the research and associated arguments which emphasize the need for reform of tertiary chemistry and whether these are consistent with those identified from the review of Australian chemical education developments (see Chapter 3).

4.2 THE ‘BIG-PICTURE’ DILEMMA

The perceived crisis in Australian chemistry was discussed in detail in Chapters 2 and 3 and it is now appropriate to assess the extent of this crisis internationally and, in particular, to review the initiatives which have been taken to remedy it.

Freemantle (2002) has argued that chemistry is crisis in the UK due to -

(the highly competitive system used by the British Government for funding universities is forcing closure of chemistry departments. (p.52)

The UK crisis in (university) chemistry is evaluated by interviewing selected Professors of Chemistry in UK universities such as Edwards, University of Birmingham who states:

Chemistry is unquestionably at a critical juncture in its development in the UK. Our subject is perceived, quite correctly, as a major facilitator in key disciplinary activities such as molecular biology, materials science and nanotechnology. However, as a core discipline, chemistry is suffering badly, certainly within the UK, as it struggles to retain ground in terms of attracting the very best of our young people. (p.31)
To quantify this ‘struggle’, Freemantle quotes figures from the University Colleges Admission Service (UCAS) which show that the number of students accepting places in first-degree undergraduate chemistry programs in the UK dropped 27% between 1994 and 2001, compared with enrolments in business management, computer science and media studies which increased by 55%, 98% and 138% respectively over the same period. Further, for the year 2002, the number of applications for entry into higher education programs in the UK is up 3.9% on 2002 applications but applications for chemistry have decreased by 2.6%. This progressive decline in enrolments in the UK over the last decade has resulted in closure of some university chemistry departments, most notably that at Kings College, London in 2003. They have become non-viable becoming increasingly non-viable since their funding is tied to student numbers. If these decline, departmental funding declines proportionately. Freemantle’s interview with Edwards continues:

_The only philosophy for an internationally competitive department anywhere in the world is to teach within an atmosphere of international -level research activities. The advanced components of any successful undergraduate program must map onto the dominant, that is, the exciting and advancing areas of research, so exposing students to the frontiers of knowledge and learning in the subject. To innovate, expand and compete more effectively, we have to find revolutionary new financing routes for universities. In particular, we must urgently find innovative and adventurous ways of strengthening our core discipline of chemistry, which I believe, has been pauperized and demoralized’. (p.36)_

The 1999 interview series with Heads of Chemistry Departments of 19 Australian universities, (see Chapter 2), echoed the dismal financial status of Australian university chemistry departments with consequential effects similar to those identified by Freemantle in the UK.

In an article in ‘The Sunday Times’ newspaper, Hackett (2004) argues that universities in the UK are in the midst of a ‘science crisis’ and that science academics are accusing the universities of ‘selling out’ on the physical sciences (known as the ‘enabling sciences’ in Australia) in favour of cheaper, more popular subjects.

Commenting further on the UK situation, Jacobs (2002) asserts that US chemistry is heading towards ‘its own critical juncture’ since there is evidence of
progressive budget cutbacks to US universities with consequential effects on infrastructure, equipment and library resources and concludes:

If the Golden Age of American Science comes to an end, it will be sad for our society and ultimately a disaster for our economy. (p.5)

The US is also experiencing the ‘flight of students from the sciences’ (Green, 1989) who makes the observation:

The declining interest in science (at the tertiary level) and the growing interest in business careers have been paralleled by a significant shift in the values expressed by college freshmen. Whereas interest in getting a general science education has declined sharply, interest in earning a higher salary shows a sharp increase. (p.479)

Naismith (2002) comments on the corresponding situation in the UK:

The seemingly inexorable decline in numbers of students in undergraduate courses in chemistry, set against increasing numbers of students overall, makes worrying reading. (p.3)

and offers three solutions -

(one is to convince the government to pay the real cost of educating students in intensive staff contact subjects like chemistry. Another is to move to a US-style liberal arts education in which chemistry is an integral part of most degrees (thereby increasing student numbers) and the third is for the chemical community to restructure itself. (p.3)

Naismith concludes that the third option appears to be the most likely outcome with ‘restructure’ translating into merging chemistry with other science disciplines and closing chemistry departments that are not sustainable as budgetary units through acute losses of commencing students. The Freemantle paper previously discussed (Freemantle, 2002) indicated that ‘chemistry department closures’ at UK universities was becoming common and in Australian universities, mergers of traditional chemistry departments into other science disciplines has become very common. Closure of chemistry departments in Australian universities has largely been avoided at the cost of the Chemistry 1 course becoming a ‘service course’ for a plethora of other sciences, particularly the biological sciences. However, the international trend
of a decline in the status of chemistry in universities is also most apparent in
Australian universities.

Adam (2005) asserts that the problem of declining student demand for tertiary
chemistry in the UK is still prevalent:

*Researchers, politicians and teachers are warning of an
impending crisis in British chemistry after a government
report (not cited) highlighted a dramatic collapse in the
number of university students pursuing the discipline.*

(p.1)

He continues:

*Chemistry – like the rest of the physical sciences – is
currently struggling to attract degree students all over
the world, according to professional societies and others.*

(p.1)

Adam believes that a critical factor in this demise of chemistry in the UK is the
closure of many chemistry departments in UK universities because of lack of demand
for chemistry undergraduate courses and a lack of government funding for their
research programmes. He continues:

*More students are using chemistry as a route to vocational
degrees such as medicine and recent advances in molecular
biology and genomics are also drawing students to the life
sciences and away from chemistry.*

(p.1)

Duffy (2004) reports on a survey of why prospective science students in the
UK are not selecting chemistry for tertiary study. Some of the reasons given include
‘chemistry is difficult to make exciting’, ‘chemistry graduates are poorly paid’,
‘difficult to get a job with a chemistry degree’, ‘chemistry was boring at school’,
‘(tertiary) chemistry courses do not reflect employer’s requirements’ and, most
significantly ‘chemistry is difficult’.

Harries-Rees (2004) looks at the current status of science education in the UK
and links the shortcomings thereof to the declining demand for tertiary science
courses and the declining interest in school science teaching as a career:

*A vicious circle has developed in the UK. Uninspiring chemistry
lessons are contributing to putting students off studying chemistry
at university and reducing the likelihood that they will return to
schools as teachers. The UK government is taking science education
seriously but there is a long way to go before we can be confident*
that chemistry teaching is truly able to inspire the scientists of the future. (p.1)

An ‘opinion paper’ (no identified author) in the prestigious journal ‘Nature’ titled ‘A discipline buried by success’ (2001) argues that:

Chemistry suffers from multiple image problems. Chemists working at the boundaries should acknowledge and celebrate their roots, while those at the core have much to celebrate too. (p.399)

There is need for a simple definition of ‘what chemistry is’ which the public at large can identify with:

Lack of an accurate and identifiable chemistry ‘brand’ means that the discipline is easily misunderstood and those working in it are frequently under-appreciated. This is the basis of the discipline’s infamous image problem. Chemists have allowed those from outside the field to characterize it – to define what chemistry is and what it is not. To the public, chemical science is too often synonymous with the industry with which it shares its name. So chemistry means belching chimneys and poisoned rivers, not life-saving medicines and space-age materials. (p.399)

The article concludes:

If chemistry is to lay stronger claims to its future achievements, more of the front-line chemists streaming across the discipline’s borders into attention-grabbing multidisciplinary research must make their voices heard. (p.399)

In a similar context, Pavlath, (2002) argues that it is time to establish a Centre for the Public Image of Chemistry which would have several responsibilities such as being a watchdog for misinterpretation of chemistry in the media and provide clarification statements and monitor new discoveries in chemistry that can have direct beneficial effects in daily life and explain in layman’s term how the public will benefit.

The paradox here is that although the chemistry profession is recognized for its long-established reputation as a leading science, its public image is such that ‘biology is more attractive and more meaningful as a useful and relevant science’. This translates directly to a reluctance to study chemistry at both the upper secondary and tertiary levels.
The demise of chemistry is also discussed by Adam (2001) in terms of an identity issue:

*In the melting pot of modern science, chemistry’s cutting edge is being branded as biology or nanotechnology.*

Adam argues that:

*While other scientific disciplines reap maximum publicity from their triumphs, chemists have seen some of their brightest moments claimed by rival fields. From the discovery of life-saving drugs to the explosion of work on carbon nano-tubes, new developments in chemistry often seem to end up being appropriated by other disciplines.*

The classic example of usurped credit is nuclear magnetic resonance spectroscopy (NMR). Chemists played a vital role in the development of NMR and its medical spin-off, magnetic resonance imaging but MRI is seen as an example of how physics can contribute to biomedical research – ‘chemistry’ is not acknowledged for its primary contribution to this cutting-edge development. Hence, there is an urgent need for an education campaign to promote chemistry and, more importantly, the meaning and significance of chemistry in the public domain perhaps via ‘a younger generation of spokespersons and writers who have a better grasp of what is happening in the rapidly evolving aspects of chemistry’. This can only be achieved if a ‘younger generation of chemists’ is appropriately trained and sustained.

Flood (2003), suggests that the declining uptake of chemistry courses in schools and universities is rationalized in terms of a fundamental paradigm shift in the public perception of science:

*In a society that has lost faith in science, how do we convince people that chemistry is a worthwhile and wholesome subject of study and that the typical chemist is not hell-bent on destroying the environment?*

Flood argues that the language of chemistry in the public domain has changed to the use of terms which have topical meaning. Terms such as ‘hydrocarbon’ and ‘synthetic’ have been replaced by ‘carbohydrate’ and ‘natural’ with the latter being much more ‘user-friendly’ than the former simply because of their colloquial usage. Thus, Flood believes, if the public image of chemistry is to change, it must be promoted in a colloquial context. Flood argues that:
Chemistry courses need to change so as to highlight the fact that chemistry has made life incomparably better for many despite there having sometimes to be a balance between technological risk and reward. Steps will need to be taken to change (chemistry) courses so that they show that chemistry plays a central role in trying to maintain a healthy, stable and well-fed world. (p.168)

This essentially is the ‘social responsibility’ aspect of chemistry which needs to be incorporated into chemistry courses.

Clee and Reed (1993) argue that in the UK the number of tertiary students studying chemistry over the decade 1980 – 1990 increased by 25% over the previous decade but this should not promote complacency:

If chemistry is to maintain this growth in numbers, certain areas need to be addressed. Teachers need to be aware of the wide variety of careers and opportunities available in chemistry so that they can advise pupils accordingly. The vital role of the chemical and pharmaceutical industries in promoting national wealth needs to be communicated to students and the educational press needs to present a more balanced view of the situation to encourage young people to view chemistry as a positive choice. There is always a danger that if the phrase ‘nobody studies chemistry anymore’ is repeated often enough, it may become a self-fulfilling prophesy. (p.28)

A letter to ‘Varsity’ – the Cambridge Student Newspaper – very effectively sums up the demise of chemistry from the student perspective (Willcocks, 2001):

While the students’ impression of chemistry as an un-sexy subject are justified, their opinions regarding the job prospects of a chemistry graduate are totally unfounded. What they fail to realize, or rather, what their careers advisors fail to tell them, is that a chemistry degree can take you anywhere. A chemist can go into any discipline but an arts student cannot go into science. The biggest challenge comes with tackling chemistry’s image as a tough subject academically. It’s true that chemistry is a demanding course using a wide range of skills. You
have to learn things and you do, from time to time, have to use numbers. (p.1)

The ultimate challenge is to present the richness, diversity, intensity, social responsibility and excitement of chemistry in the Chemistry 1 course but not at the expense of eliminating the essential basic chemistry and the inherent mathematical skills necessary for its fulfilment.

Hills (2003) discusses the importance of teaching from contexts:

*Contexts involve people, risks and decisions. These are human considerations full of human interest. Case studies of chemical inventions, chemical disasters and chemical triumphs are interesting because we can learn from the mistakes. Chemistry then comes to life. Case studies have become the backbone of modern medical education. They need to become the backbone of chemistry teaching and learning. Contexts are invariably as interesting as contents.* (p.84)

Hills infers that teaching chemistry using only facts, knowledge content, theoretical descriptions and the certainties of simplification leads to student disinterest in the subject, especially commencing tertiary science students and gives chemistry a ‘bad name’. Effective teaching of chemistry in context can bridge the teaching and learning nexus and empower students to experience real-life chemistry.

Smaglik, (2000) believes that some twenty-two new frontiers in basic chemistry as identified by Lippard (MIT), provide a ‘road-map’ for future directions of chemistry research which will drive other leading-edge fields of science such as biotechnology and nanotechnology and simultaneously lead the ‘quiet revolution’ in image revival of chemistry. The elements of the ‘road-map’ are carefully constructed to include basic concepts of chemistry applied to frontier areas of research. Two examples illustrate this:

*Create chemical products and processes that do not require the use or generation of hazardous substances and use renewable resources.* (p.808)

and:

*Master the chemistry of caged species, releasing at will a guest entrapped in an appropriate host in the gas, solid or solution states by introducing a chemical, magnetic or electric field.* (p.808)
Both of these examples require a basic knowledge of molecules and chemical bonding with the first essentially embracing the principles of green chemistry and the second embracing state-of-the-art synthetic chemistry, whereby the host-guest synergy is exploited to synthesise new molecular systems of pre-determined size and properties which mimic many bio-molecular systems. The road-map overall focuses on specific ways to manipulate molecules and reveals the elegance of basic chemistry with the commercial reality of applied chemistry. It is argued that if research in chemistry is aligned with these recommendations, funding from both internal and external sources is more likely to eventuate. The ‘implied agenda’ here is that the ‘frontiers of chemistry’ are intuitively founded on basic chemical principles and these must be elegantly included in chemistry courses at both the secondary and tertiary levels.

Smaglik further believes that there is considerable evidence that chemical companies seek employees with basic science training and the frontier research zones identified by Lippard are especially attractive to the chemical industry. Skills such as the ability to manipulate chemical bonds, the development of more efficient catalysts and the development of ‘solvent-less’ systems, are all cost – effective initiatives which meet the current ‘zero waste’ and ‘zero emissions’ objectives of the chemical industry. Hence, Lippard’s road-map essentially endorses the enabling role of core chemistry in chemical education. The challenge is to teach it in such a way that its enabling characteristic is fully understood and appreciated by students.

However, Rice, (2000) in the UK asks -

(\textit{w}here will we find future generations of \textit{undergraduate} chemists?)

\textit{Why, from the large number of students who study A-Level Chemistry each year, can we not find a larger cohort of students with the enthusiasm for studying the subject at University level?} (p.150)

Rice proposes that the answers to these questions relate to the students’ experiences at A-Level, the nature of university chemistry courses and the job prospects and the image of chemistry and concludes that the lack of desire to follow chemistry at the tertiary level is attributable not to the standard of teaching but to the nature of the material that has to be taught. The focus of the problem is therefore curriculum based at Years 11 and 12. Rice probes this issue further and queries whether the A-Level chemistry curriculum is relevant to the students’ experiences and if the subject material captures their imagination and challenges their intellects. He further queries whether A-Level chemistry is perceived as ‘too-hard’ and whether the content of A-
Level chemistry courses bear too close a resemblance to the intensive first year university chemistry courses of the recent past. Further, Rice argues that the present A-Level courses do not present a positive image of chemistry to a wider audience than those who want to pursue the subject at university.

The Rice critique of A-Level chemistry is in harmony with a critique of the current VCE chemistry course levied by Cross and Fensham (1996) (see Chapter 3). It appears that both the UK and Australian chemistry school certificate courses lack a ‘social responsibility’ emphasis which ensures their remoteness from the human experience of science and their inherent inability to reveal chemistry as a ‘consumer-friendly’ and an ‘environmentally-friendly’ science.

Not surprisingly, Rice drew a flurry of responses from the UK chemistry teaching fraternity. Lee (2001) writes:

*I would like to see a concerted effort from teachers, universities and the UK chemical industry to show school chemistry students how much the science of chemistry and the mental discipline of chemistry play a vital role in nearly every facet and sphere of employment. We must accept that not all degree students will work in the chemical industry but be prepared to demonstrate and celebrate the achievements and rewards that chemistry graduates are reaping in so many other fields. The importance of industry and its links with all sectors of education cannot be understated. We live in an age where information is power: we must demonstrate to students by all means possible the rewards that chemistry can offer.*

(p.8)

Bailey (2001) addresses the image of chemistry:

*While academics generally regard course content as the most important aspect of the degree, almost certainly it has the least impact on a student’s degree choice. This is because they are overwhelmed by ‘guidance’ extolling the virtues of dozens of degree courses at dozens of universities. With this information overload, it is small wonder that the course title (eg biomolecular engineering instead of chemistry with biochemistry) is likely to be the deciding factor. It is however, the perception of chemistry by the public in general, and by students in particular, that is*
most affecting student uptake. If we could inspire students with our subject and demonstrate that chemists enjoy successful and rewarding careers, then the future of chemistry would be rosy. (p.8)

Dickson (2001) directs the ‘blame’ onto the curriculum:

Students today are very aware of the world around them. Yet, what they are exposed to when they start studying chemistry at A-Level in most cases and with most curricula is an antiquated set of facts and figures that have no rhyme or reason in the modern world. We need to keep abreast of the chemical world and this needs to be integrated and woven into a coherent and fully exciting experimental subject. If we do not, then we will fail in our attempts to attract students into our courses. (p.8)

Wallace (2001) argues for a new vision:

While university recruitment numbers start to fall, the tendency to think introspectively invariably leads to local ‘fire-fighting’ tactics even when the fire may already have taken a serious hold, not only locally, but nationally and internationally. What is needed is a new vision for chemistry: a vision to see and promote chemistry in the context of today’s world: a vision to see chemistry as a vehicle for a scientific education for a wider audience: a vision to encourage large numbers of graduates from university chemistry departments to enter fields of work linked tenuously, if at all, with chemistry and this to be considered acceptable and indeed be the ‘norm’: vision to see the urgent need for a safety net for traditional chemistry to be a broader discipline of molecular science, organised by chemists, which would address this new wider remit of the traditional discipline and attract more A-Level chemistry students and a vision for the design of radically new undergraduate chemistry curricula to encompass these aims. (p.9)

Wallace (2001) graphically concludes:

(h)owever, only a metamorphosis in the traditional form of chemistry currently taught in universities will prevent
ourselves becoming dinosaurs of the 21st century, or at best, being found only in the ‘scientific Galapagos Islands’. (p.9)

In a late conclusion to this debate initiated by Rice (2000), Dickson (2004) makes a plea for ‘real chemistry’ for our students:

*We chemists really need to overhaul our image if we are to halt the trend of declining chemistry student numbers in higher education. There is ongoing concern that the undergraduate chemistry curricula have been lulling students to sleep for decades with the same lack-lustre lectures and textbooks. The main problem is that the curriculum writers (ie the people who influence school chemistry students) and some on the education committees of such organizations have their own agenda on what should be in the curriculum and seem to have little regard for what is good for the students or what is real chemistry. Many of them tend to be out of touch with the problems students have with learning chemistry. We all should have the same goal – to communicate to our students the real and relevant world of chemistry.* (p.38)

It is a sobering revelation that many of the issues highlighted in this debate initiated by Rice resonate with similar issues raised in conjunction with Australian secondary and tertiary chemistry courses as discussed in Chapter 3. The undeniable message is that not only is there an immediate review of the typical international school certificate chemistry course but, equally important, is a review of the Year 1 tertiary chemistry course. Thus, the Rice debate essentially endorses the rationale of the present project not only in terms of preserving chemistry in Australia but also, ensuring the central role of chemistry internationally.

In a provocative but visionary discourse, Wallace, (2003) argues:

*Chemistry is a mature discipline with a distinguished pedigree and a long tradition, but times are changing and student numbers in chemistry are declining. The need for a reappraisal of what constitutes chemistry and a chemistry education at the beginning of the new millennium, is apparent. I believe there are a number of factors currently which have come together that make such a re-evaluation vital, at the start of the new millennium, if chemistry*
is to continue to maintain its undergraduate population, both now and into the future. (p.83)

Wallace quotes the Federation of European Chemical Societies (FECS), (2002) in affirming that there is much activity affecting the ways in which science (including chemistry) is being taught at the secondary level across Europe. Chemistry teaching is moving towards context-based learning, emphasis of skills rather than facts and independent learning and projects. Further, much effort throughout Europe is being directed to in-service science teacher training.

Wallace further quotes Harvey, (1999) in defining the rationale and ideals of higher education which apply unilaterally to higher science education:

The primary purpose of higher education is to transform students by enhancing their knowledge, skills, attitudes and abilities while simultaneously empowering them as lifelong critical, reflective learners. (p.84)

In his preamble for change, Wallace asserts:

The world is changing rapidly and will continue to change rapidly. Higher education should play a role in accommodating, facilitating and leading change rather than resisting it. (p.85)

To further develop his argument, Wallace quotes the ‘Roberts Review’ (2002) on the supply of high quality scientists and engineers in the UK:

The relatively large and growing number of students studying scientific and technical qualifications is largely due to increases in the number of students studying IT and the biological sciences. (p.85)

Wallace proposes that the decline in uptake of chemistry at the tertiary level has three broad explanations – the subject itself, its image and its career prospects. He qualifies this proposal by developing supportive arguments for each explanation. With respect to the ‘subject’, its popularity rating is declining due to an inflexible assessment system, an over-prescriptive curriculum that lacks relevance and coverage of recent scientific developments, poor laboratory facilities and, most particularly, poor career advice both at the secondary and tertiary level. He also relates ‘subject popularity’ to the quality of chemistry teachers:

For many who teach chemistry, particularly at the secondary school level, chemistry is no longer fun! Budget restrictions, and more importantly safety issues and legislation, have taken away
the spontaneity and the ‘let’s try it and see’ approach to experimentation. Add to this the curriculum ‘which has to be covered’ and ‘the fundamentals which must be taught’ both in schools and universities, give chemistry a bulkiness that detracts from its inherent fascination and the diversity of an all-permeating subject. The live issues and the varied and exciting applications that are still being developed, come late in the day of learning, by which time many students have switched off and gone elsewhere. (p.86)

To those who look at the subject from the outside, it can seem a world of inaccessible technical terms and incomprehensible formulae. Further it suffers from the disadvantage that the invisible world of molecules is remote and as such cannot be perceived by the senses. Finally, one should not forget the major influence played by the inspirational chemistry teacher as a motivator for a student to continue to study chemistry. (p.87)

In this context, Wallace 2001 has shown that in the UK there is an increasing trend for chemistry at the upper secondary level to be taught by non-chemists and this inevitably has a major impact on students’ perceptions of the discipline. Wallace asserts that the ‘way chemistry is taught in schools’ is an issue we ignore at our peril in the context of ensuring a future for chemistry.

With respect to the ‘image’ of chemistry, Wallace (2003) affirms:

*Chemistry always appears to be dogged by a poor image. Advances in chemistry tend to go unreported or under-reported. However, there is always excellent news coverage of every chemical accident.* (p.88)

He continues:

*Chemistry has a communication problem. There is a general lack of insight that chemistry is part of society in the ‘good’ sense rather than part of society in the ‘bad’ sense. Chemists are very well capable of communicating but they haven’t learned to communicate outwards.* (p.88)

Wallace qualifies such communication ineffectiveness results in the public believing that ‘medicines are not made by chemists’, ‘fashion textiles have nothing to do with chemistry’ and ‘healthy food is a benefit to society – produced without chemicals or chemical technology’. These perceptions are the tyranny of communication gap and show a need for a ‘science (education) for all’.
With respect to ‘career prospects’, Wallace (2003) argues that -

\textit{(c)h}emistry must be seen to be a career provider. Long-term career prospects (in chemistry) need to be good. Within science, courses increase and decrease in popularity and this is to be expected, but if chemistry is to hold its position, students must be able to identify readily the advantages of having a chemistry degree.  

\textit{(p.88/89)}

Wallace continues:

\begin{quote}
Chemistry is at the heart of the sciences but we have allowed it to become ‘high-jacked’. Chemistry as a subject of our lives is not being recognised – ‘the chemistry belongs to somebody else. What is molecular biology if it is not the chemistry of large molecules? (p.89)
\end{quote}

Wallace also argues for a re-examination of the relevance of the secondary school chemistry syllabus content:

\begin{quote}
\textit{What if students eventually make it to university? Do they want more of the same – facts first and then the interesting applications later? Almost certainly not. (p.89)}
\end{quote}

He continues this debate with a critique of the ‘traditional’ chemistry curriculum:

\begin{quote}
\textit{If we now decide to alter in a radical way how the curriculum is delivered, then it may not be possible to cover all of the subject matter, and indeed other topics that have been set aside may need to be re-included. Change always has ramifications. ‘Traditional’ should not mean ‘set in history’. ‘Traditional’ in some ways is synonymous with ‘the subject’ and I would submit that there is a more radical way of delivering chemistry, where chemistry is used as a vehicle for delivering a scientific education. Clearly there is still a need for a core of traditionally educated chemists for the foreseeable future. However, school and university chemistry departments must not be tied to past definitions that exclude some of the most exciting new chemical advances.} (p.89)
\end{quote}

Wallace thence proposes that -

\begin{quote}
\textit{(t)he alternative chemistry, the vehicle, would be an approach where the emphasis is more on the scientific method and how it can be used and applied to broader and indeed seemingly}
\end{quote}
unrelated areas. It would seek to look at concepts in a wider arena. (p.89)

He then poses the questions:

Is school chemistry trying to achieve different goals to that of university chemistry and therefore is the transition more marked than it need be? At the university level, what are we doing to prepare students for the varied situations that they will encounter in permanent employment? (p.90)

Wallace concludes by calling for reform of chemical education which are of significance to the present project:

I suggest that we must do the following: consolidate, metamorphose, diversify, re-badge and think radically. (p.94)

Wallace proposes that the ‘traditional chemistry curriculum’ ‘has to go’ and that metamorphosis can be achieved by transforming ‘structure and bonding’ to ‘chemical architecture’ and ‘atomic structure’ to ‘the chemical micro-world’. The chemistry curriculum should diversify to include biotic chemistry and supramolecular chemistry (among many others) and re-branding of chemistry can be achieved by emphasizing it as a ‘molecular science’. Wallace believes that these transformations are not simply a matter of semantics but of perception with chemists sending the right signals to potential students of the exciting world of chemistry as the central molecular science. Finally, he proposes that an industrial placement should be a compulsory component of university chemistry courses and further that chemistry school teachers should have some industrial experience as part of their overall training. Wallace believes that this direct connection with the chemical industry at both the secondary and tertiary levels of chemical education is the most important criterion for the long-term survival of the discipline.

This treatise is a comprehensive critique of the status of chemical education and many of the issues discussed in terms of raising the profile of chemistry internationally are consonant with similar issues with respect to the status of chemistry and chemical education in Australia.

There are several recent articles relating the status of the (global) chemical industry with the career prospects for graduate chemists and the correlation of this factor with the demand for tertiary chemistry courses. A ‘cover story’ in the journal ‘Chemical & Engineering News’ (2005) (no identified author) discusses the ‘world
chemical outlook’ for 2005 and predicts that the ‘demand for chemicals’ in the US, Canada, Latin America, Asia and Europe will continue to be ‘strong’ but that there is likely to be ‘some moderation’ at least in the rate of demand for chemicals on the global market. This suggests that there will be even greater moderation for the demand of trained chemists globally – thereby suggesting no immediate remediation of a global decline in demand for tertiary chemistry courses. This is endorsed by Raber (2003) who argues:

*With the slow economy (in the US) persisting for another year, unemployment for chemical scientists is high and demand is soft. New chemical graduates can expect a long job search and fewer offers.*  

(p.2,3)

Harries-Rees (2005) argues that it is necessary to ‘get the balance right’ in terms of employment of chemical graduates in the chemical industry:

*Innovation is a key factor in corporate success. Research in the chemical industry has traditionally been centralized and technology-driven. This is now moving to a more open, decentralized, market-driven approach. Having the right people at each stage of the process and understanding how they can work together is as critical as the innovation ideas themselves.*  

(p.1)

This perspective is endorsed by Frantz (2003):

*When recruiting graduates, companies look for motivated students who are well-trained in (chemistry) and have good practical skills and they favour degree courses that include a placement in industry.*  

(p.1)

And:

*In addition to proven bench skills, companies also look for good problem-solving and analytical skills, the ability to present and communicate science and someone who is willing to accept challenges, think outside the box and learn.*  

(p.1)

These mandatory requirements of chemistry graduates by prospective employers present further challenges for the designers of tertiary chemistry course curricula and, in particular, the teaching methodologies and learning outcomes of such courses. It is
particularly important that these principles are founded in the Chemistry 1 course and progressively developed throughout the chemistry major programme.

Hurd (1993) makes a plea to restore the productivity and visibility of science education research and to frame a more provocative and formative role in directing efforts to modernize science teaching. A 10-point research agenda is proposed which has potent significance for chemical education research, most appropriately in recognizing the social responsibility of chemistry and the democratization of science education to achieve responsible citizenship. A further significant research agenda item in this context is the modernization of science courses by selecting subject matter from the total range of contemporary research areas. Both of these are consonant with the proposals of Wallace (2003) but it seems that from the latter critique, little progress has been made in terms of such chemical education research. Thus, in terms of international chemical research, there appears to be ‘a crisis of confidence’ prevailing and a general reluctance to enact reforms.

Finally, a recent press release by the Royal Society of Chemistry argues for a more realistic approach by UK universities in supporting chemistry as an essential component of the academic curriculum (RSC, 2004). The RSC argues that closures of departments is very short-sighted since chemistry, both directly and indirectly, has a direct impact on the health and wealth of the nation:

*Data show that investment in chemical science teaching and learning results in a real return for individuals and the country. The chemical sciences provide the underpinning core expertise for most scientific and technological developments and continue to make enormous contributions to social, cultural, economic and intellectual advances.*  

(p.1of1)

The essential message of this press release is remarkably similar to the RACI ‘Enabling Sciences Initiative’ directed at the Australian Federal Government in 2001 – pleading for additional financial support and recognition of the ‘enabling sciences’, most notably ‘chemistry’ (see Chapters 1, and 3).

Thus, the ‘big picture’ dilemma with respect to chemistry and chemical education from an international perspective is remarkably similar to the ‘big picture’ dilemma experienced with Australian chemistry. This dilemma is not unique to chemistry but to the enabling sciences generally and is characterized by a lack of impact of chemical education at all levels on society generally such that society has at
best a limited understanding of the values of chemistry and at worst, a perception that chemistry is irrelevant to a sustainable world. The international challenge is not only to address such a widespread misconception but also to revitalize chemical education at all levels to extol the social responsibility of chemistry in all its facets and in all its applications.

However, as a balanced postscript, not all parts of the world are or have experienced the ‘big picture’ dilemma in chemistry and chemical education. Most notable in this respect is the status of chemistry in South East Asia and particularly in Singapore and Malaysia. This author has personal experience of chemical education in Singapore having been a Senior Teaching Fellow in the Department of Chemistry at the National University of Singapore (NUS) from 1990 to 1994 and having recently been invited to review the Department of Chemistry at Universiti Kebangsaan Malaysia (UKM), Kuala Lumpur, Malaysia in terms of benchmarking of chemistry courses and assessing the standard of research in that Department.

The reasons for a thriving chemistry profile in both NUS and UKM are complex but are related to a large, sustainable academic staff complement (by comparison with staff numbers in Australian and UK universities), most of which are research active, excellent teaching facilities, particularly with respect to well-equipped laboratories and IT facilities and, most significantly, direct interaction and involvement of the (local) chemical industries in undergraduate and postgraduate teaching. Both of these universities have well-established international benchmarking of chemistry courses, particularly the Chemistry 1 course as an integral part of the internal quality control process.

In the Chemical Education section of the Singapore International Chemical Conference (11) (SNIC-2), (2001), Hor delivered the Ang Kok Peng Memorial Lecture and reviewed the history of the Chemistry Department at the National University of Singapore from its origin in the University of Malaya to its incorporation into the National University of Singapore. This was a visionary paper in which Hor reviewed the development of chemistry in Singapore and its future directions and he argued:

*Our (NUS Chemistry Department) immediate future is best summarized by the three “I’s”, interdisciplinary, internationalization and impact. It is no longer sufficient to strengthen our traditional pillar areas (Organic, Inorganic, Physical, Analytical and Theoretical).*
It goes beyond these areas which cut across traditional boundaries to embrace new areas such as organometallic chemistry, surface chemistry, biochemistry and computational chemistry. The future of chemistry and ‘Singapore chemistry’ is no different, lies not so much in the development of established fields in chemistry but much more on how chemistry communicates with and integrates into emerging domains of knowledge.

In the same conference, Ching and Ng (2001) presented a paper on the evolution of the chemical industry in Singapore, indicating that this industry is the second largest contributor to the Singapore economy and has consistently provided employment for University degree and diploma graduates. Singapore is the third largest oil refining centre globally and is recognised globally as an industrial chemical hub. The authors conclude:

In the next phase of global industrial evolution, it is anticipated that knowledge and intellectual resources will become key competition benchmarks. The Singapore government is underscoring the importance of chemical research capabilities and highly skilled scientists and engineers to bolster this ‘software’ aspect. The Institute of Chemical Sciences has been established specifically to address this role.

The significance of the chemical industry to the Singapore economy and, in particular, the respect and support of the Singapore government for science and science education are highlighted by an article titled ‘Island of Opportunities’ by Marchant, (2001). A tangible reflection of such support for science is the creation of a ‘Biopolis’ in Singapore which will contain 20,000 to 30,000 scientists in a self-contained complex - complete with accommodation, schools, shops and entertainment/leisure facilities. However, the Singapore government recognizes that the ultimate success of such a bold venture depends on a continuous supply of well-trained scientists both from within Singapore and from overseas.

Chemistry at the Universiti Kebangsaan Malaysia is also flourishing. The reasons underpinning such status are similar to those apparent for chemistry at NUS. In particular, five chemistry programs are offered at UKM – traditional (mainstream) chemistry, chemical technology, oleochemistry, food science and food science with
management. The latter four courses have an ‘industrial placement’ component which directly integrates UKM chemistry courses with the Malaysian chemical industry.

It is relevant to identify why chemistry is flourishing in South East Asia as compared with its demise in other parts of the world. It is apparent that many of the ‘constraints’ placed on chemistry in Australian Universities which are discussed in Chapter 5, are not an issue with respect to chemistry in Singapore and Malaysia. Two factors are paramount in contributing to the present status of chemistry in South East Asia, adequate and continuing financial support of the respective governments for science and effective interaction between post-secondary educational institutions and the chemical industry. Essentially, the ‘big picture’ dilemma in this part of the world is essentially eliminated by the positive attitude shown towards ‘science’ by the political, social, business and educational sectors and the effective integration of these to achieve a progressive socio-economic outcome.

4.3 DEVELOPMENTS IN INTERNATIONAL CHEMICAL EDUCATION AT THE PRE-TERTIARY LEVEL

In the context of the present research, it is inevitable but regrettable that the bulk of chemical educational research has been directed towards the secondary level. However, developments in chemical education at this level have an obvious impact on chemical education at the tertiary level and hence such developments on the international scene need to be briefly reviewed here, particularly in terms of the impacts on international tertiary level chemistry. However, it is not appropriate here to present such a summary review but to be aware of the essential international developments in chemical education which have a direct relevance to the present project in terms of a reform of the Year 1 tertiary Chemistry course. It is also necessary to be aware of such developments which correlate or complement corresponding developments in Australian chemical education which have been discussed in Section 3.3. The most significant issue in the context of chemical educational developments at the secondary level is the extent to which these impact on chemical education at the tertiary level and it is this aspect which has guided the present review which is reported in Appendix 5.
4.4 DEVELOPMENTS IN INTERNATIONAL CHEMICAL EDUCATION AT THE TERTIARY LEVEL

The international chemical education literature is vast, rich and illuminating by any measure of quantity and quality and hence it is impossible to undertake a comprehensive review of developments in this arena even over the previous ten-year time span which is judged to be relevant to the present project. Hence the present review is confined to the authors’ appraisal of international chemical education developments which are of critical significance in influencing tertiary education in chemistry both in terms of curriculum design and educational philosophy.

4.4.1 An historical perspective of chemical education
A most appropriate starting point of such a review is to have a defining image of international chemical education some 15 years ago as revealed by a summary of the FIPSE (Fund for the Improvement of Postsecondary Education) Lectures of 1989 entitled ‘New Directions in Chemical Education’:

*Chemical Educators are broadening their horizons. They are developing courses that integrate chemistry with other sources and with the humanities. They are reaching out to their counterparts in other parts of the world through international conferences and by helping their students to participate in international competitions and they are more committed to educating their students on the relation of chemistry to political, social and environmental issues.*

(p.98)

The summary report continues –

*(h)owever, chemical educators must act quickly in response to several serious challenges. A scientifically literate citizenry is needed in a technologically advanced society and yet many of our students lose interest in science long before they are high school sophomores. There is disturbing evidence that US students are poorly educated in science and that fewer of them are choosing to pursue careers in science and engineering.*

(p.98)

This vision and reality of chemical education prevailing in 1989 is largely true in 2004 globally and the ‘serious challenges’ identified in these FIPSE lectures are still
as realistic today as they were some 15 years ago – perhaps with additional intensity and remedial urgency which predicate and endorse the present project.

Rice (2002) argues that many of the vexing issues which challenge chemical educators today have posed similar challenges to generations of their predecessors. He qualifies this assertion by reference to Charles Edward Munroe, a leading US Professor of Chemistry in the first half of the twentieth century and a passionate chemical educator:

For more than 30 years, he welcomed each incoming class to George Washington University with his inspiring talk ‘Why Study Chemistry’. He quoted six reasons which he believed applied as much to teaching chemistry as to learning it. (p.1292)

Munroe’s reasons for studying chemistry, as announced in 1925, were – ‘for its economic value, that is as furnishing a means of livelihood’; ‘to enlarge one’s vocabulary’; ‘as a means of culture’; ‘as a means for improving the condition of mankind by ameliorating his environment; because we are completely subject to its laws and our lives depend for every moment of our existence upon the orderly progress of the many chemical reactions going on within and without our bodies and also because every commercial transaction in which we may take part, except barter, is based upon chemical analysis’ and ‘one may study chemistry from patriotic motives, hoping to serve the nation’s needs both in peace and war’. Some eighty years later, this rationale for studying chemistry is still pertinent.

4.4.2 The Chemistry-Biology connection

There has been much international debate on the progressive loss of identity which chemistry has experienced as biology has become prominent as a leading science. Mason (2002), has stated the obvious that -

(t)he study of biochemistry and the applications of chemistry to biology are increasingly important at the (secondary) college level. Some (US) universities are offering an integrated organic-biochemistry course at the Year 1 level. This initiative may attract more potential majors (in chemistry) and it integrates general chemistry with physical chemistry and biochemistry. (p.1289)

This is fundamentally a call to widen the boundaries of traditional chemistry at the tertiary level to embrace other sciences which are not perceived to be related to chemistry. A university course such as that described by Mason not only reveals the
boundless scope of chemistry but also, and perhaps more significantly, its enabling characteristics.

An Editorial in the Journal of Chemical Education (2002) laments that -

(\textit{w}ith such large numbers of biology students in our undergraduate courses, one might expect that the myriad connections between chemistry and biology would be emphasized, but often they are not. (p.1287)

A 2002 report of the US National Research Council is quoted:

\textit{Biological concepts and models are becoming more quantitative and biological research has become critically dependent on concepts and methods drawn from other scientific disciplines. The connections between the biological sciences and the physical sciences, mathematics and computer science are rapidly becoming deeper and more extensive. However, the ways in which most future research biologists are educated are geared to the biology of the past. Connections between biology and other scientific disciplines need to be developed and reinforced so that inter-disciplinary thinking and work become second nature.} (p.1287)

In this context, it is believed that:

\textit{Cross-disciplinary teaching is something that neither chemists nor biologists can do alone and it is perhaps the most difficult aspect of improving undergraduate education in the sciences. Pedagogical collaborations similar to collaborations in research can greatly enhance our ability to create truly useful learning environments for students and to help those in other sciences to do the same. We owe it to ourselves and to our students to redouble our efforts to enhance communication and collaboration with teachers of biology and other sciences.} (p.1287)

Price and Hill (2004) have argued that cross-disciplinary teaching is critical to addressing the declining image of chemistry globally:

\textit{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.  

The essential message of this paper is that chemical educators should regard the ‘biology takeover’ as an opportunity and via cross-disciplinary teaching, incorporate a significant biological bias into traditional chemistry courses so as to reveal the synergic relationship between these disciplines, thereby enriching the teaching and learning perspectives of both simultaneously.

4.4.3 Chemistry learning and teaching methodologies

There are a plethora of quantitative studies which show that the traditional lecture is an ineffective teaching methodology. Among those which relate specifically to chemistry, the studies of Johnstone and Su (1994) and Jenkins and Chaudhuri (2003) are significant in that both stress that strategies must be found to convert lectures from a passive into an active learning environment by including the students in the information transfer process. This can be achieved most simplistically by holding dialogue with the students as the lecture progresses and also by asking students to undertake simple tasks, either oral or written either at the commencement or at the end of each lecture. This latter strategy has been adopted successfully by Jenkins and Chaudhuri in teaching a stepwise organic synthesis. A number of questions are asked of the students as the lecture progresses which probe in depth the students’ understanding of the organic chemical principles which relate directly to the synthesis in question. This interactive approach was found to be particularly successful in communicating general chemical principles to specific chemical scenarios.

Cole et al. (1998), ask the question ‘Does university chemistry need to be so boring?’ and given that -

(c)hemistry is a pivotal science, fundamental to so much that is exciting and inspiring in the world around us – what is wrong with current chemistry courses? 

These authors cite the all too familiar shortcomings of tertiary chemistry courses – students perceive little relevance of core material to the real world; syllabuses are overcrowded allowing little space for exciting and challenging chemistry; students
perceive that chemical knowledge is more important than the acquisition of transferable skills; the link between practical work and theory is less than obvious; insufficient emphasis is given to the social aspects of chemistry and many students in ‘Chemistry 1’ have insufficient mathematical skills, a problem which is not seriously addressed in chemistry courses.

Cole et al. (1998) have developed a ‘Chemistry 1’ course based on several integrated thematic units consistent with the Salters’ approach (a UK based course) to learning chemical concepts with revision and reinforcement at appropriate stages. They believe that encountering a particular concept in several different contexts helps students to make the all-important connections in chemistry. They conclude:

What is all too apparent from our efforts to date is the enormity of such a root and branch overhaul of just the first year university chemistry programme. Cooperation on a national level is needed if there is to be a transformation in the appeal of university chemistry to the post-16 age group. (p.56)

Moyes (2003), argues that:

University chemistry courses need to become broader if they are to attract the burgeoning numbers of students seeking higher education. There is a need to compete for the best, or at least a share of the best students available. The challenge is to make chemistry fascinating, attractive and inspiring to the prospective student if competition with equally intriguing alternatives such as medicine is to succeed. (p.33)

He continues:

Research is not the only driving force for change. Many of the current views of chemistry arise from ill-informed antagonistic judgements from a public unfamiliar with chemical principles and methods. Academic chemistry has a duty to provide as many scientifically literate graduates as it can to help redress the balance. (p.33)

Moyes concludes that the current problem provides an opportunity to develop chemistry courses that foster independent learning by teaching students to manage information and, in particular, emphasise the social responsibility of chemistry. This summary message is echoed throughout the international chemical education
literature but appears not to have been heeded by Australian chemistry academics. Perhaps this is the real core of the problem in Australia and is brought about by the latter in general not being familiar with the international chemical education literature. This was revealed in the interviews with Heads of Chemistry Departments as summarized in Chapter 2.

However, Dawson (1994), argues that:

*Although science education research is a growing area, it is a fragile plant compared with other forms of scientific research.* (p.104)

Dawson has undertaken a survey of completing PhD’s, MPhil’s and MEd’s in science education in the UK over the period 1970 to 1990 and has shown that the number of PhD’s in science education over the period 1984 – 90 has remained between 20 and 30 and has further commented that science education research in the UK does not receive sufficiently wide recognition to make an impact on the declining interest in the physical sciences. A similar scenario is true in Australia, whereby chemical education research in Universities does not have the appropriate status to receive appropriate national and international recognition. This sad scenario was also apparent from the interview project summarized in Chapter 2.

There is a rich international literature on teaching and learning processes in chemistry which significantly impacts on the present project, once again in the context that limited such research has been undertaken in Australia. James (2003), argues that the richness and rigor of chemistry is derived from its origins:

*Knowledge of chemical processes is older than human civilization.*

*Without the basic knowledge of how to turn clay into pottery or how to obtain metals from ores, civilization could never have come about.* (p.31)

James believes that the history and philosophy of chemistry is as exciting and compelling as the cutting-edge advances in the chemical sciences and that the former must be included in chemistry courses. He continues:

*The history of chemistry, especially since the late 18th century, illustrates how much chemistry has changed in its organization, use of language and the way that we exploit and disseminate chemical knowledge. Above all, it reveals how differently we view the world that chemistry produces.* (p.31)

The inherent challenge in this essay is to incorporate ‘that different view of the world that chemistry produces’ into (at least) the tertiary Chemistry 1 course so that students
are aware that chemical knowledge is constantly evolving and that they are a critical component of knowledge acquisition and dissemination – they are at the nexus of chemical teaching and learning.

Hanson and Wolfskill (1998) have outlined methodologies for improving the teaching and learning process in General Chemistry. These are based on the premise that ‘process’ and ‘student-centred learning’ are currently the missing elements in the General Chemistry curriculum and that there needs to be an appropriate integration of chemistry, mathematics and physics concepts within the curriculum and that the course structure overall needs to probe the thinking processes of students and their ability to develop mental models. The authors also strongly advocate the use of computer technology to improve the teaching and learning process via learning and understanding through computer-based interactive discovery. Critical thinking skills should also be developed in such a course. It is apparent from the interviews with Heads of Australian Chemistry Departments conducted in 1999 and discussed in detail in Chapter 2, that much more research needs to be undertaken into the teaching and learning environment of tertiary chemistry since this directly impacts on the effectiveness and quality of chemistry courses and their attractiveness to students.

Garratt and Overton (1997), believe that:

> Critical thinking exercises for chemistry undergraduates are a useful way of developing transferable skills since most undergraduates concentrate on acquiring knowledge at the expense of developing skills. The tend to accept chemical ‘facts’ without question and, in extreme cases, they believe that chemistry or indeed science, always provides definitive answers rather than being a procedure for extending knowledge of the natural world.  

(p.79)

These authors believe that critical thinking in chemistry involves four types of exercise: identifying a conclusion, assessing argument, critical reading and making judgments. It is believed that such a critical thinking methodology should be incorporated into chemistry course curricula, especially at the Year 1 tertiary level.

Whilst it is generally recognized that students are at the nexus of the teaching and learning processes, Johnstone (1999), believes that –

> Research in chemical education reveals that what is taught is not always what is learned.  

(p.45)
He asserts that this phenomenon is particularly apparent with respect to chemistry:

In chemistry, our senses cannot help us to form the concepts
of element or compound, atom or molecule, electron or proton.
We are operating in a very different intellectual area. These
concepts are not tangible in the way that most other concepts are. (p.46)

He continues:

The other problem with chemistry is that the tangible macro-science
(the appearance, state, smell, colour etc) has little obvious link with
the micro-science at the molecular level. One of the big challenges
that took place in the 1960’s in relation to chemical education was
to imply that to be an honest discipline, chemistry had to teach the
macro, the sub-micro and the symbolic language of the subject
simultaneously. Psychologically this was probably a disaster. (p.47)

He concludes:

We have an unusual subject to teach and we need a great deal of
insight and knowledge of the learning process to make it assessable
to our students and to share with them our enjoyment of it. (p.48)

The dilemma is that tertiary chemistry teaching in general continues to be traditional
and conservative and the imperatives of the 1960’s, as identified by Johnstone, are
still present currently but the challenge of understanding the learning processes of
chemistry and being able to impart these to chemistry students has largely not been
achieved with the result that students are shying away from chemistry. This is a
further critical finding of the present research and will be further developed in
Chapters 6, 7 and 8.

The ability of chemistry students to translate between the macro and micro
world of chemistry has been qualitatively investigated by Nicoll (2003). Specifically,
the study has focused on the encoding that students use to develop molecular models
which are macroscopic interpretations of the sub-microscopic structure of molecules.
The study found that -

(s)tudents do not necessarily have a developed or accurate mental
image of how atoms are arranged in a specific molecule; students
do not understand periodic trends; students do not necessarily pay
attention to bonding when building molecular models; students do
not necessarily improve their understanding of these concepts as
they progress through additional chemistry courses and some students try to build more into their models than are included in model kits. 

This study alone identifies the gulf that exists in the teaching and learning of perhaps the key concept in chemistry – an ability to transcribe the macro world of matter into the micro world of atoms and molecules.

In this context, Kind (2003) believes that -

(\textit{m}any students hold a variety of misconceptions about chemical bonding that arise partly from their interpretation of commonly used teaching strategies. 

Kind believes that chemistry students can be assisted to understand why elements form different types of bond by using a ‘cognitive conflict strategy’ which depends on showing students that bonding depends entirely on atoms forming compounds in the most energetically favourable way that ‘costs’ the least energy. In this way, bond energy is seen as the driving force for bond formation and a ‘concept linkage’ learning approach results.

However, the concept of chemical bond energy and its consequences invokes knowledge of mathematics if the necessary learning outcome is to be achieved. Doggett (1997), highlights the commonly held view –

(\textit{s}tudents entering chemistry undergraduate courses are constantly being criticized for being mathematically inept. 

He further recognizes that such criticism acts as a deterrent to studying chemistry and believes that -

(\textit{u}niversity chemistry courses must therefore be designed to ensure that the students’ level of enthusiasm is not diminished and the current modular courses must offer the flexibility for dealing with the students’ lack of mathematics ability. However, the consequences for teaching a modern chemistry degree course are becoming more challenging because all branches of chemistry rely increasingly on mathematical techniques, either in modelling chemical processes or in processing experimental results. 

Doggett believes that the traditional mathematically orientated chemistry core topics are progressively becoming optional topics, especially at the Year 1 level. Topics such a quantum mechanics fall into this category resulting in a qualitative interpretation of
atoms and molecules being presented at the Year 1 level. This is an inevitable outcome of the change in student ability that is apparent at the present time and this is a further critical factor driving change in the ‘Chemistry 1 course’. However, Doggett concludes that mathematics is at the centre of chemical modelling and -

\[(i)\text{t is this excitement and appreciation of the beauty in our modelling of chemical phenomena that we must pass on to our students. This is why the teaching of mathematics in a chemical context is so important.}\quad(p.106)\]

The implied challenge is to teach the appropriate mathematics at an appropriate level in a chemical context and it is apparent that this is not easily achieved by chemistry academics.

There is a vast literature on teaching the ‘special type of mathematics’ required to ‘balance’ chemical equations. Murphy and Hathaway (2003) believe that this is best achieved by a problem-solving approach. They believe that -

\[(b)\text{y appreciating the origin of the ‘number of reactive species’ and the way it can vary depending on the types of reaction involved and by using a general working method to calculate the stoichiometric factors in a reaction, students can balance chemical reactions relatively easily.}\quad(p.23)\]

Although this method predicates some knowledge of ‘numbers’, it transforms the balancing process from a purely mathematical exercise into a precise chemical expression written in mathematical terms but in the language and symbolism of chemistry.

There is an equally vast literature on the ‘conceptualisation’ of chemistry. Dawson (1993) believes that -

\[(w)\text{hile science educators now recognize the importance of developing students’ cognitive skills, this emphasis seems to have been at the expense of the knowledge base. To redress the balance, the use of concept maps is suggested to help students organize their knowledge. In chemistry, concept maps can be used to construct conventional chemical meanings.}\quad(p.73)\]

The conceptualization literature in general is highly supportive of concept maps for connecting chemical concepts and for placing these concepts in context with
‘everyday’ chemistry. Concept maps also condense and organize knowledge and therefore structure the learning process.

4.4.4 Use of IT in the learning and teaching of chemistry

There is a rapidly growing international literature on the use of computers in the teaching of chemistry – trivially referred to as ‘teaching chemistry the smart way’. Clark and Rest (1996) believe that -

\begin{quote}
(\textit{w}hen faced with a range of abilities (of students), traditional teaching methods are ineffective. Self-paced learning, delivered with new interactive technologies, is an ideal way of narrowing the gaps (in students’ abilities) to produce a more manageable, homogeneous teaching environment.\end{quote}

This assessment seems plausible but lacks research evidence. It seems inevitable that the use of information technology in the teaching of chemistry at all levels will rapidly increase. However, the authors’ interviews with Heads of Australian Chemistry Departments in 1999 as summarized in Chapter 2, whilst recognizing and endorsing this trend, argued very strongly for a measure of caution to be applied in that student surveys of the effectiveness and quality of the Chemistry 1 course had consistently revealed that the preferred method of course delivery was ‘face-to-face’, with computerized revision programs and self-paced computerized tutorials being accepted as second-best options. However, such surveys had highlighted the need for the inclusion of more multimedia usage to facilitate an understanding of a wide variety of chemical concepts and to illustrate the essential and common experimental techniques.

In the latter context, Ramme (1995) has described a simulator for studying thermodynamics and kinetics and this is but one of an ever-increasing array of such simulators available. This paper does however reveal how by the use of a simulator, complex physical chemistry concepts can be made easy to visualize and hence understand at an elementary level and thereby encourage students in the learning process.

Garrett and Overton (1996), have suggested that short scientific papers are a useful teaching aid in chemistry and are a realistic supplement to conventional supporting textbooks. Further, they argue that -

\begin{quote}
(\textit{w}ell-chosen scientific papers are motivating simply because they add variety to the student learning experience, help to reinforce\end{quote}
chemical theory, bring together concepts from different areas of theory and are a convenient way of introducing students to the primary literature. (p.138)

Stone (2003), takes the concept of ‘undergraduate research’ as a teaching and learning experience to a new level and challenges the commonly held view that –

(new entrants to the various (UK) chemistry degree programs lack the necessary scientific background to pursue a research project with any degree of success. (p.140)

Stone (2003) argues that by introducing minor research projects at the undergraduate level -

the students become active protagonists in the scientific process rather than being passive onlookers. More importantly, it also provides invaluable CV material to which all students will have an eye on and provides an opportunity for revitalizing chemistry recruitment strategies, to which we should all have an eye on. (p.140)

This latter initiative has been introduced in the ‘Direct Honours’ chemistry program at the National University of Singapore whereby the most able chemistry undergraduates complete an Honours degree in three years instead of the conventional four years. The Stone suggestion has considerable merit for enriching chemistry undergraduate programs and rewarding the most capable students. However, there is a great need for research into IT learning in tertiary chemistry before a judgement can be made about its effectiveness. In the context of this curriculum study, the progressive increase in the use of IT in teaching chemistry is noted but will not be a significant issue as it deals with pedagogy except where animated computer modelling allows new and interesting chemical topics to be taught.

4.4.5 The effectiveness of practical work in tertiary chemistry

There is an intensive international literature on the effectiveness of practical work in undergraduate chemistry courses. The overwhelming consensus of opinion on this issue is that chemistry is quintessentially an experimental science and therefore it is intuitively obvious that practical (laboratory) exercises are an essential component of any undergraduate chemistry course. However, it is apparent that chemistry laboratory exercises associated with tertiary chemistry courses are progressively reducing in scope, intensity and number due to institutional financial constraints which impinge on both staffing and the necessary equipment and the intransigent constraints imposed by Occupational Health and Safety legislation.
However, Marthie et al. (1993), whilst agreeing that practical work is an intuitively essential learning experience for chemistry students, have strongly put the case for a well-defined framework for undergraduate chemistry laboratory exercises which clearly defines the aims, objectives and laboratory skills associated with such exercises. Further, the current (UK) assessment procedures for chemistry practical work are not effective for accurately assessing the level of laboratory skills attained by students nor do they reflect the true understanding level of students of the exercises carried out. This is due to students following the procedure set out in the manual as a ‘cooking recipe’ without any understanding of what they are actually doing. Thus, these authors argue that laboratory manuals need to give more information on experimental setups, safety precautions and experimental techniques and less detail on how the experiment should be carried out so that the students have to work out such detail based on their accumulated knowledge. This has the added advantage of students connecting their theoretical knowledge with experimental outcomes.

Bennett (2000) recognizes the dichotomy associated with chemistry practical work:

The majority of students studying chemistry at university have no intention of pursuing chemistry as a career. In these circumstances is it appropriate to design a practical programme that is solely directed to the training of professional chemists? On the other hand, it is essential that all science students appreciate and experience the constraints, potential and tensions of the investigative process. For chemistry, this necessarily involves a laboratory experience, though investigative work is certainly not confined to the laboratory. (p.49)

He believes that although essential, reform of tertiary chemistry practical work is essential:

Most of what goes on in first-year undergraduate chemistry laboratories is not experimentation but rather a training in manipulating equipment, handling chemicals and developing techniques. (p.49)

Bennett agrees with Marthie et al.(1993) that the way forward is for students to see laboratory work as much more than a ‘hands-on’ exercise and that chemistry laboratory exercises should be planned against a skills analysis grid so that transferable laboratory skills are attained by the completion of the course. Laboratory
Manuals should be designed as a ‘flow chart activity’ so that students have defined direction in the experimental work asked of them. Bennett strongly supports interactive, computerized pre-laboratory tutorials to ensure that students have sufficient chemical knowledge to undertake the practical exercise.

However, Johnstone and Letton (1990) argue that -

*(r)*esearch results show that the psychological loads placed on students by laboratory manuals are the main reason for unsatisfactory laboratory performance. *(p.9)*

They continue:

*It is little wonder that students during the experimental stage take the road to sanity, following the manual instructions line by line without much effort to consider the theoretical aspects which ought to illuminate and inform their observations. It may be that most of the learning, if any, takes place at the reporting stage when the student reviews what has been done and tries to interpret the results. However, it may be possible to produce a satisfactory report without any real synthesis of theory, observation and interpretation having taken place.* *(p.11)*

Similarly, Byrne (1990), argues for more effective practical work:

*The consensus view is that much chemistry practical work serves only to develop manipulative skills and is not very effective in helping students grasp concepts.* *(p12)*

He suggests writing the instruction manual in such a way as to promote a problem-solving approach rather than asking students to follow a recipe and concludes that –

*(l)*earning can be enhanced by reduction of information overload and that by appropriate approaches to writing instruction sheets, improvements can be effected in both cognitive and affective aspects of practical chemistry. *(p.13)*

Bishop (1995), takes this idea one step further and suggests that –

*(g)*roup work on selected themes offers a challenging alternative to the traditional ‘cookery book’ approach of undergraduate chemistry practicals. The themes should be related to subjects that the students can relate to themselves and therefore become interested in. *(p.131/2)*
This small selection of the international literature dealing with the effectiveness of tertiary chemistry practical work is sufficient to highlight the associated universal problems. There is general agreement that practical work is an essential component of tertiary chemistry courses and must be retained despite financial and regulatory constraints. However, chemistry practical exercises need to be more interactive and to involve the student directly in the learning process rather than simply asking students to follow a well-defined procedure which is guaranteed to produce the desired result. Learning is achieved both from positive and negative outcomes and many of the landmark developments in science have emerged from negative experimental results. In terms of this research, it will be assumed that practical work is an integral part of the Chemistry course and such inclusion is discussed in Chapters 7 and 8.

4.4.6 Developments of tertiary chemical education and the influence of professional chemical societies

It is particularly relevant to briefly summarize the international developments which have taken place with respect to the ‘tertiary Chemistry 1’ course and, more especially, the support provided in enacting change by professional chemistry societies and by political authorities.

The leading chemical educator in the world today, Peter Atkins, has given an intriguing insight into the ‘future of physical chemistry’ in a rapidly changing chemical education environment (Atkins, 2000). He predicts that physical chemistry will survive as a distinguishable component of chemistry but some ‘core topics’ such as Group Theory and the intensity of thermodynamics will have to be eliminated from the Chemistry 1 course because of their mathematical complexity:

*The core of the current attitude to our subject is the central role of mathematics and the fear that it inspires. I think the incorporation of mathematical software into our courses is enormously important because it will take the pain out of mathematics and augment our ability to portray material graphically.* (p.39)

Atkins concludes his vision of chemistry with the inspiring claim that -

*(e)xpanding knowledge simplifies understanding. Enhanced knowledge opens doors and eliminates the need to learn detail.* (p.39)

Herein lies the ultimate challenge, to teach Chemistry 1 in such a way that knowledge of chemistry is progressively enhanced without the need to learn specific detail and involve mathematical manipulations.
Butcher et al. (2003) have to some extent taken up the ‘Atkins challenge’ and devised a ‘student orientated’ introductory chemistry course which they call ‘Sparky Intro-Chem’. The development of this course has been supported by the National Science Foundation and includes – mathematical problem-solving skills, the interpretation of graphical and tubular data, understanding and using chemical concepts, scientific reasoning and development of positive attitudes towards science. The course is comprised of innovative modules, interactive laboratory experiments and workshops. The course coordinators found that by replacing some conventional examinations with projects helps students discover the relevance and excitement of chemistry.

In order to enhance the ‘student orientated’ approach to learning, the Department of Chemistry at York University has recently introduced a ‘skills logbook’ for chemistry undergraduates to use as a way of encouraging them to exploit their time at university more fully (Lowe, 2000). The skills included in the logbook include, communication, numbers application, information technology, working in groups, self-improved learning and performance and problem solving – all with particular relevance to learning chemistry. It has been found that -

\[(t)\text{he logbook draws their attention to the skills being developed by particular parts of the course, thus encouraging them to become more reflective in their approach both to developing skills and learning chemistry.}\]  

\[(p.134)\]

This is a significant step forward in enhancing the (chemistry) learning process and therefore has considerable merit.

Perhaps the most visionary statements on the future of chemistry and, in particular, the future of chemical education, emerged from the American Chemical Society (ACS) national convention held in New York in 2003 and summarized by Berresen (2003). One of the principal aims of the convention was -

\[(t)o\text{ explore what the content of an undergraduate chemistry curriculum should be so that it reflects modern chemistry and ensures that chemistry and future chemists meet the challenges of the 21st century.}\]  

\[(p.142)\]

Some of the major conclusions from the convention were that -

\[(c)\text{hemical education should prepare chemists for the challenges and opportunities of the future, not the past and chemical education}\]
should stress research programs that challenge students to make meaningful contributions to society.

No single science is advancing technological development but through multidisciplinary research, chemistry plays a vital role in technological progress and developments across other scientific fields as well as its own.

The chemistry tertiary curriculum should provide additional transferable skills rather than just basic chemistry knowledge. A curriculum that includes and promotes both emerging and societal topics will help attract more students.

Chemistry is a field of science that is growing more interdisciplinary with its boundaries ceasing to have any meaning in the future. Any chemistry curriculum re-think should emphasise how the ‘new chemistry’ is done while retaining the core defining features of the discipline. This should be delivered in a manner that uses the contexts that show the subject’s relevance and problems faced by society and engages students in active learning. (p.142)

Finally, at this convention, Atkins (2002) (see Appendix 4) proposed his 9-point ‘diet of chemistry’ – the fundamental simple ideas on which chemistry is based. These important pointers to a new chemistry curriculum and particularly the Atkins ‘diet of chemistry’ will be addressed in Chapters 6, 7 and 8 and Atkins ‘simple ideas of chemistry’ philosophy is one of three major components of a new curriculum framework for Chemistry 1 which is proposed by the author.

A Sri-Lankan writer, Gunawardhan (2003) argues that -

(t)he survival of technology is dependent on science and hence science curricula have to be revised to include the interfaces with other areas so that the newest advances can be understood and used productively towards research and development. (p.27)

He argues that the boundaries of chemistry need to be redefined to include the ‘new chemistry’ phenomenon relating to nanotechnology, laser chemistry, femtochemistry among many others.

Siriwardena (2003) and Ashmore (2003) both separately argue for chemical education to encompass ‘sustainable development’, thus suggesting that chemistry is included in the emerging ‘sustainable science’.
Another international influence on the ‘Chemistry 1’ course is the introduction of a new type of science degree across Europe – the ‘Chemistry Eurobachelor’, an initiative of the European Chemistry Thematic Network with the support of the Federation of European Chemical Societies (Gagan, 2004). This initiative is a part of the wider ‘Bologna Process’ – a reform package for the unification of university degree structures throughout Europe. At present, the Chemistry Eurobachelor and the Bologna Process have not been supported by the UK university network but this appears to be a very significant initiative in addressing the lack of attention given to the structure of chemistry undergraduate degrees and of the associated curricula particularly at the Year 1 level.

The Higher Education Funding Council for England (HEFCE) is aware of the core problem relating to the demise of chemistry (Roberts, 2003):

In most developed countries in the world, chemistry student numbers in higher education institutions are in decline with the decline in numbers of students studying chemistry, physics, mathematics and engineering in UK universities has reached worrying levels – ‘no funding’ means ‘no departments’. (p.86)

[In this context, Thompson (2000), laments the closure of the Chemistry Department at Royal Holloway, University of London, as a further outcome of the UK government’s current funding policy on science education.]

Like the Royal Society of Chemistry (RSC), the American Chemical Society (ACS) recognizes that chemical education is at the focus of the development of the chemical sciences and supports chemical education on a ‘K-12’ basis (Nalley, 2002). The ACS supports the famous series of Gordon Conferences and publishes the leading chemical education journal ‘Journal of Chemical Education’, which is in the top 5% ranking of international chemistry journals in terms of ‘impact factor’. The ACS is, without doubt, the major influence on chemical education globally, particularly in terms of cutting edge teaching and learning initiatives.

Naturally, there is an organization which represents chemistry and chemists globally and this is the International Union of Pure and Applied Chemistry (IUPAC). This organization has as its mission statement -

‘to advance the worldwide aspects of the chemical sciences and to contribute to the application of chemistry in the service of mankind. In doing so, IUPAC promotes the norms, values, standards and ethics of science and advocates the free exchange of
scientific information and unimpeded access to scientists to participation in activities related to the chemical sciences’.

IUPAC is the principal global organization responsible for promoting chemical education universally.

Naturally, in a computer-literate age, chemistry and chemical education have a global electronic communication network as summarized by Town (1998) and Walter (1998), President of the ASC, who discussed communication within the ‘global chemical community. Similarly, Hollingworth (2001) has described chemical education communication in the South Pacific Region, the most notable of these networks being the Asian Chemical Education Network (ACEN), which publishes the e-journal ‘Chemical Education Journal (Japan)’ and publishes regular e-newsletters on all aspects and developments in chemical education in the Asia-Pacific region.

Kosby and Khurma (2001), have described ‘Chemistry at the University of the South Pacific’ – which has many campuses spread over several South Pacific islands. Networking with other universities in the Asia-Pacific region is essential for USP to maintain its image as a leading centre for chemistry and chemical education in the region.

Universities globally are ‘internationalizing’. Ghiggino (1999), argues that -

\[\text{(t)he key to success for universities facing an internationally competitive environment is to attract the most talented local and overseas students. The internationalization of science education will be a defining feature of the new millennium and it will be important for Australian tertiary institutions to compete effectively in the international arena if they are to maintain and enhance their reputations.} \]

(p.35/6)

With respect to the demise of chemistry globally, this is indeed a very significant challenge but it is none-the-less an essential element of its ultimate resolution.

Perhaps one of the most far-reaching reviews on science education ever undertaken was the ‘Roberts Review’ of 2001. The charter of the review was to investigate ‘The supply of people with science, technology, engineering and mathematical skills’ – in the UK. The findings of this review were submitted to the UK Government and provided quantitative evidence in support of the global demise of the ‘enabling sciences’ in the educational domains and firmly laid the blame at the ineffectiveness of the science education system in the UK. The Review strongly urged
government to increase funding for science education across the sector and specifically highlighted an alarming level of neglect for science teaching infrastructure (laboratories) in the school and university sector. This issue will be critically discussed in Chapter 5, which addresses the acute institutional constraints faced by the tertiary sector in delivering a sustainable level of chemical education in Australia.

The ‘chemistry cause’ in Europe appears particularly strong, supported by a major promotional campaign (Short, 2002). In Belgium, this has taken the form of wide distribution of a booklet ‘Wow Chemistry! – The Discovery of your life’, which was designed to lure young people into the chemical profession.

The European Commission (EC) is committed to ‘science in society’ (Roberts, 2003):

(1)It has become clear to us that the public needs to be actively involved in developing scientific agendas because society is becoming increasingly dependent on science. (p.143)

The EC has established the ‘Gago Enquiry’ whose mandate is to -

(i)dentify specific actions that can be implemented at a local or though cooperation among member states to stimulate the number of young people taking up science careers. (p.143)

Other cooperative chemistry ventures in Europe include the European Chemistry Teachers Network (ECTN) which is inclusive of secondary and tertiary chemistry ‘teachers’ and communicates electronically. The Federation of European Chemical Societies (FECS), founded in 1970, provides a powerful voice for chemists and the chemical sciences in Europe through its activities and development of policy and issue of definitive publications. There is also ‘The Alliance for Chemical Sciences and Technology in Europe’ (AllChemE), which is inclusive of a number of organizations such as The European Chemical Industry Council and it is most well-known for its publications grouped around the theme ‘Chemistry : Europe and the Future’, and in the context of this project, the AllChemE publication ‘The changing marketplaces for chemistry and chemical engineering in Europe : emotion, education and economics’ is most timely since it maps career opportunities for chemistry graduates. In particular, this paper emphasizes the diverse range of career opportunities available to those who have a tertiary qualification in chemistry. This paper is complemented by a paper presented at the European Association of
Institutional Research Forums by Harvey (1999), which discusses the general relationship between higher education and employment at the turn of the previous century.

4.4.7 Some ideas from international chemical education conferences

It is generally recognized that perhaps the most significant indicators of advances in chemical education emerge from international conferences and thus it is appropriate to close this long discussion of international developments in chemical education with a brief overview of the most enlightening of these advances. As early as 1987 at the Ninth International Conference on Chemical Education, Cole was arguing that ‘Good Chemistry is easily understood Chemistry’ and his views on linking chemistry to society were pioneering at that time (Cole, 1987). At the International Conference on Science Teacher Education and Training for the 21st Century, (1997), this author presented a paper ‘Chemistry Teaching – Addressing the immediate crisis and possible future challenges’ (Appendix 4). It was actually this presentation which precipitated the present research project. At Pacificchem 2000, several presenters, most notably, Breslow (2000) emphasized the ‘centrality of chemistry in the sciences’ and that chemistry is at the core of the molecular sciences. The papers in the chemical education section of this conference emphasized these themes and the international need to revitalize chemical education, particularly at the tertiary level. At the Singapore International Chemical Conference 11 (SICC-2) (2001), it was evident that ‘chemistry in Singapore’ has not experienced the same degree of ‘demise’ as experienced in the UK, Europe and Australia. This is probably due to a different chemistry learning and teaching environment in Singapore, most notably due to an appropriate level of government funding of science education and an excellent interactive relationship between the secondary and tertiary sectors with the Singaporean chemical industry (Hor, 2001). At the 17th International Conference on Chemical Education (17 ICCE), Beijing, 2002, Atkins keynote address expounded his ‘diet of chemistry’, premised on the view that chemistry is made up of ‘a few simple ideas’ and that ‘the world is full of the wonders of chemistry’. These ‘core ideas’ will be discussed in detail in Chapters 6, 7 and 8, since they are critical to the development of a new curriculum framework for the Chemistry 1 course. Other keynote addresses focused on widening the boundaries of chemistry to include nano-science and the medicinal sciences and ‘how to teach’ ‘chemical biology’. The present author presented a paper at 17 ICCE titled ‘Learning from the Past: Looking
towards the Future’, (Appendix 4) which predicated the design of a new Chemistry 1 curriculum framework with a strong social responsibility thrust. Finally, the author also presented a paper titled ‘Shaping the future of Chemical Education to meet the challenges of the new millennium’ (Appendix 4) at the 31st Annual Session and 61st Anniversary Celebrations of the Institute of Chemistry – Ceylon, Colombo, Sri Lanka (2002). Other keynote presentations at this conference emphasized the need for an integrated approach to international chemistry teaching and learning.

4.5 CONCLUSION

This review of the international chemical education literature has revealed that the ‘demise of chemistry’ is not a unique phenomenon localized in Australia but is experienced in the UK, throughout Europe and to some extent, in the US. However, it is most apparent that the ‘remedial comeback’ is more evident internationally than it is in Australia and the reasons for this are complex, but obviously are related to funding, public image of chemistry, support of chemistry professional societies, emphasis and impact of chemical education research and interactive strategies with the chemical industry. Curriculum design of secondary and tertiary chemistry courses play a role as does professional development of science teachers and chemistry academics. With respect to the former, the Salter’s Chemistry Curriculum for school chemistry appears to have made a major impact on attracting students to chemistry, whereas conventional Nuffield (UK) A-Level chemistry courses and HSC (Australia) chemistry courses appear to have the opposite effect. With respect to the latter, globally it appears that ‘chemical education’ is a respected academic professional pursuit, whereas in Australia, this has a somewhat inferior image in the academic community. Significantly, the ‘demise of chemistry’ in Asia and SE Asia in particular, appears to be a ‘non-issue’ due to a different cultural environment for learning and adequate government support for education coupled with a strong interactive relationship with the chemical industry.

At the tertiary level internationally, there are many and varied indications that ‘change’ is essential but the ‘indicators for change’ are incompletely defined. Whilst it is generally agreed that ‘university chemistry’ needs revitalizing, there are only scant indications of how this can be achieved. It is apparent that the major indicators for change are the ‘socialization and simplification’ of the Chemistry 1 course with
emphasis on a ‘student-focused’ course content and a flexible approach to the teaching and learning thereof to cater for students with a wide range of previous chemistry knowledge and cognitive skills.

Thus, overall, the international chemical education literature supports the rationale for the present project. It also provides some pointers as to the sort of changes that are need in order to improve the image of chemistry and the enjoyment of learning it. Some constraints on such changes are also identified – the acute financial problems facing chemistry departments in UK universities and the consequential closure of many of these with more closures predicted in the present decade. There are clear indications of changes required in the learning of teaching of chemistry at the Year 1 level with recognition of the ‘difficulty of chemistry’, particularly the associated mathematical concepts. There is agreement that the learning and teaching of chemistry can be enhanced with the use of IT and, particularly, the inclusion of more practical work, particularly at the Year 1 level. Indeed, the recognition of practical work as an essential inclusion of tertiary chemistry curricula is consistent with chemistry retaining its status as an experimental science. In designing new chemistry curricula, it is essential to heed the requirements of the chemical industry in terms of chemistry graduates having the ‘right type’ of skills and ability to solve problems, work in teams and have advanced communication and interpersonal skills. Most significantly, it is important to recognize in designing tertiary chemistry curricula that chemistry is inexorably linked to technological progress. These drivers propelling reform of tertiary chemistry are discussed further in Chapters 6, 7 and 8 in terms of the author’s proposals and design of a new curriculum framework for the Chemistry 1 course in Australian universities.

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CHAPTER 5

CONSTRAINTS ON THE TERTIARY CHEMISTRY
LEARNING AND TEACHING ENVIRONMENT

5.1 INTRODUCTION

To enact ‘change’ in the generic sense means overcoming the ‘constraints’ which impede change. The principal aim of this chapter is to review and discuss the constraints which may impede change in chemical education in Australian universities.

The purpose of this chapter is fourfold. Firstly, to define the limits of what might be considered ‘plausible reform’ of the Chemistry 1 course by identifying the boundaries of what is plausible with the current level of difficulties experienced by tertiary chemistry departments in Australian universities. Secondly, to separate these identified reforms into an order of manageability. Thirdly, to place the constraints into a number of categories and fourthly, to indicate that these identified constraints will be taken into consideration in designing a new curriculum framework for the Chemistry 1 course to be discussed in Chapters 6, 7 and 8.

The scope of this chapter is confined to Australian tertiary chemistry education. Overall, only constraints which impact either directly or indirectly on the learning and teaching chemistry tertiary environment will be considered.

5.2 CONSTRAINTS POTENTIALLY AFFECTING REFORM OF TERTIARY CHEMISTRY

The Head of Chemistry Department interviews discussed in Chapter 2 revealed a number of constraints which they believed impacted on the learning and teaching environment of Chemistry 1 thereby impeding change to the course. These constraints have been grouped into six categories which are discussed in this section.

5.2.1 Politically imposed constraints

The Federal Liberal Government undertook a major reform of ‘higher education’ in Australia in 2001 and the ‘white paper’ ‘Higher Education at the Crossroads’ was published in 2002 (Nelson, 2002). This document has led to a plethora of higher education reforms which will come into force in 2005. The most
notable of these is deregulation of the ‘Higher Education Contribution Scheme’ (HECS) which means that from 2005, universities will be able to charge a HECS supplement on all courses except ‘nursing’ and ‘teaching’ by up to 25% of the government-regulated HECS fee. Essentially, this means that ‘higher education’, like the health system in Australia, has become a ‘user-pays’ system. It is true that the government has introduced a range of scholarships, loan systems and ‘student learning entitlements’ to overcome some of the impact of higher HECS fees for tertiary courses but these initiatives are not immediately perceived as a softening of the imposition of increased course fees.

The immediate impact of deregulated HECS fees on tertiary chemistry courses is likely to be severe. Science courses in Australian universities are expensive to run and sustain, largely because of the ‘experimental nature’ of such courses. Science teaching laboratories are particularly expensive to establish and maintain and over the last decade at least, the extent of the ‘practical’ component of tertiary chemistry courses has been progressively reduced. This has been recognized by the RACI Accreditation Committee, which has stipulated the minimum number of hours of experimental chemistry which must be included in chemistry courses for these to attain RACI accreditation. It is inevitable then, that Australian Universities which intend to maintain a ‘science emphasis’ will have to impose the full 25% HECS increase for science courses and this inevitably will be a further deterrent to students selecting chemistry for (major) tertiary study. There has been much debate on the perception of universities charging less than the full 25% HECS subsidy in terms of the ‘value’ and ‘standard’ of their courses. In general terms, it appears that most Australian universities will be forced to impose a ‘HECS surcharge’ uniformly on all courses from 2005 onwards to overcome the progressive lack of appropriate government funding by the Federal Government over the last decade. Thus, it appears at this stage that the ‘Crossroads reform package’ imposes a range of implied constraints on the learning and teaching tertiary chemistry environment – the full impact of which is yet to be realized.

One of the most forceful responses to the ‘Crossroads reform package’ has come from Osborne (2003) who calls for an ‘arrest of the decay of diversity in higher education’:

If we believe in universities as focal points for scholarship generally, as well as training grounds for the workforce, we
need to articulate a clear, urgent and persuasive case before the infrastructure support for the traditional fields is allowed to slide down the path of irretrievable decay. (p.16)

and in concluding that the package will not significantly increase the (Commonwealth) financial support for universities in the next few years, asks -

(h)ow will basic science attract sufficient funding to serve as a foundation for innovations in applied science? The notion of a national investment to ensure continued diversity surely needs urgent consideration before it is too late. Whilst it is perfectly reasonable and legitimate to demand that universities now play a strong role in providing an expert workforce in relating to the community and in contributing to national priorities, this should not be at the expense of their traditional capacity to enrich all fields of human endeavour. The need to find a formula that will support both of these objectives seems to me to be one of the great challenges of the day. (p.16)

Osborne (2002) also comments on the role of governments in higher education:

 Because of their financial support, governments have a direct interest in the activities of the higher education sector. This has effectively put an end to any genuine autonomy on the part of universities. Governments (via the ’Crossroads reform package’) are now seeking ‘productivity gains’ and, by raising expectations that every part of the university will be cost effective, it is undermining the diversity of the institutions. (p.4)

He concludes:

For the health of society at large and universities in particular, it is surely time to recognize that a knowledge-based society must transcend work-skills and that some significant fields of knowledge deserve to be maintained even if they cannot be cost effective.

Inevitably then, although the ‘Crossroads reform package’ is to quote Nelson (2002) ‘the most comprehensive review of its kind for more than two decades which will inject new life and vitality into the higher education system’, it brings with it a suite
of constraints which need to be carefully managed internally to effect overall positive learning and teaching outcomes in the sector. These constraints are camouflaged in the document by promises of increased funding to the tertiary sector over the next five years but with strict criteria being applied. Thus, although universities will be awarded additional ‘DEST-funded’ places in specified disciplines, universities will be penalized (financially) for exceeding or not meeting the enrolment targets (set by the Commonwealth). Also, as identified by Osborne, DEST will expect all parts of the university system to be cost-effective and will impose regular quality audits of university operations at the academic, administrative and management levels.

It is generally recognized that universities are differentiated from other types of teaching institutions by their ‘teaching’ being ‘informed’ by research. The Federal Government has recognized that research is an important element in achieving its ‘knowledge nation’ status in the 21st century by announcing its ‘Backing Australia’s Ability’ package (BAA-1) in 2002 and an update in 2003 (BAA-2). This package aimed to boost Australian research, development and innovation by providing major additional funding for research over a five-year period. It was stated that the BAA-1 package was a response to the concern that Australia was ‘falling behind’ in technology development in an increasingly competitive world environment and the recognition that success in the 21st century will depend predominantly on the innovative capacity of nations, their industries and their research and educational structures. The aims and strategic objectives of BAA-1 are stated as -

(t)o encourage and support innovation and enhance Australia’s international competitiveness, economic prosperity and social well-being. Our success in these areas will reflect how well Government, business, education and research institutions work productively together to realize our national potential. (p.1)

BAA-2 (2003), in addition to reporting on the achievements of BAA-1 since its inception, detailed the major initiatives to be implemented in 2005 – 2006, the most important of which from the perspective of this research was -

(t)o implement the recommendations of the 2003 science teaching and science teacher education review. (p.96)

The aim of this review (Lawrence and Palmer, 2003), was stated as:

The study was influenced by the view that society of the 21st century will need not only people specifically trained for

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science and technology-based industries, but will need all its members to have a reasonable grasp of science and technology to live in a technologically advanced world. Teachers skilled in the sciences and mathematics and skilled in engaging students in learning in these fields, will become increasingly important in satisfying the nations’ need for a solid broad-based education inclusive of the sciences. Further, teacher preparation must address both specialist and generalist teaching of science, mathematics and technology in primary and secondary schools. Our teachers in 21st century Australia carry the weighty Responsibility of delivering courses to sustain a technologically literate society.

(p.ix)

The report found that existing teacher training programs in Australia were inadequate to meet these requirements but perhaps the major problem is that talented science, mathematics and technology students are not being attracted to the teaching profession. Thus the resulting constraint on the chemistry learning and teaching environment is compounded by students being ‘switched-off’ from chemistry at the critical secondary/tertiary interface because chemistry curricula at Years 11 and 12 not being sufficiently engaging and not being delivered by teachers with a chemistry qualification or background. It therefore seems that the constraint experienced at the tertiary level is an inheritance from the secondary level. This was identified by Heads of Chemistry Departments (see Chapter 2) as being a major reason for students not selecting chemistry as a course of study at the tertiary level.

Australia’s Chief Scientist, Robin Batterham (2002) has also emphasized the need for teaching technology at the secondary and tertiary levels:

*The growing levels of wealth in the world are increasingly based on knowledge-rich products. For Australia, our choices in life now ultimately depend on how rapidly and effectively we pursue a more knowledge-intensive society. Technology is pivotal in shaping our future. The role of science now extends far beyond gaining knowledge and making discoveries to becoming a critical part of global competitiveness. The standard of living within Australia ultimately depends upon our success in developing and implementing technology.*

(p.10)
Although both the Royal Australian Chemical Institute (RACI) (White, 2001), and the Federation of Australian Scientific and Technological Societies (FASTS), (Fell, 2002) both support the BAA-1 and BAA-2 initiative, they agree that this is only the start to ensuring a sustainable ‘knowledge-based’ nation based on scientific and technological literacy and hence the Commonwealth needs to provide more funding for science and technology education if its stated aim is to be achieved early in the 21st century.

The politically imposed constraints are all essentially related to the need for increased funding for tertiary science education, for university science department infrastructure, for increased numbers of qualified science teachers and for additional financial relief structures to offset the increased fees for tertiary education. The present Commonwealth Government initiatives in these areas fall short of the necessary levels to overcome the implied constraints and at the same time reduce access opportunities for tertiary students thereby compounding the problem of present declining student interest in tertiary chemistry courses.

5.2.2 Budgetary constraints

In terms of pressures on university science departments, Rice (1998) has argued that -

*(u)niversity science is in danger of spiralling out of control.*

*Science departments are being subjected to pressures from all quarters. Falling budgets, a switch from basic to applied subjects, a decline in student demand, expectations that staff can carry even greater loads and confusing signals from Government all contribute to the pressure.* (p.27)

Little has changed in the intervening years since this statement was made as was revealed by Evans (2001) who undertook a simple but most revealing review of the ‘health’ of Australian university chemistry departments. It is relevant to summarize some of the key findings of this review which highlight the budgetary constraints facing 21st century Australian university chemistry departments. Student/staff ratios are a common measure of the ‘state’ of chemistry departments. Evans found that -

*(t)otal (chemistry) student population numbers across the university sector are constant within the statistical year by year fluctuations but there has been a 27% decline in the number of academic chemistry staff in 2000 compared with 1990. The number of support staff in 2000 was less*
than two thirds of the number of support staff in 1990. No chemistry department has been protected from staff reductions and consequential increases in student/staff ratios. (p.17)

Heads of Chemistry Departments also highlighted increasing student/staff ratios as a consequence of a contracting academic staff compliment enforced by departmental budgetary constraints (see Chapter 2). The constancy of overall chemistry student numbers was rationalized by a progressive increase in Year 1 non-chemistry majors with a concomitant decrease in chemistry majors at the Year 1 level compounded by marginal retention rates in subsequent years. The trend towards ‘chemistry’ becoming a ‘service provider’ was also highlighted in these interviews.

On the shrinkage of chemistry departments, Evans argues that -

(1)he size of a chemistry department is important in an academic discipline as broad as chemistry. Without a sufficiently broad range of academic expertise, students necessarily obtain a more specialized ‘parochial’ degree which cannot compete with North American or European best practice. Many chemistry departments have lost their identity. Too many chemistry departments are sub-critical being unable to teach the broad essentials of an undergraduate degree in organic, inorganic, biological, physical and theoretical chemistry. You simply cannot cover these subject areas at an undergraduate level with 5 academic staff or less and yet departments with zero to 5 academic staff are the third most common ‘department’ size in Australian universities. (p.16/17)

Hence, student/staff ratios, departmental size, support staff compliment and departmental operating budgets are all inter-related and are all critical constraints on chemistry departments and these are consistently identified as factors driving the ultimate demise of chemistry in Australian universities. [However, the University of New South Wales has recognized the importance of chemistry in its Faculty of Science and has established a School of Chemical Sciences within a reconstructed Faculty of Science (Lamb, 2001) which is comprised of the former School of Chemistry and the Department of Food Sciences which is to be accommodated in a new building. This is certainly the only such development of its kind within the sector.]
The interviews with Heads of Chemistry Departments revealed further consequential constraints of declining operating budgets (see Chapter 2). A direct consequence of a diminishing number of academic staff and support staff in a chemistry department is that laboratory sessions have been progressively reduced, particularly at the Year 1 level. The RACI Accreditation Committee is concerned that many tertiary chemistry courses which it has previously accredited may no longer meet the prescribed minimum number of hours of laboratory sessions per course and it is currently undertaking a survey to assess this. In an attempt to address the shortfall of available teaching staff, some Heads of Department have encouraged and introduced electronic teaching methodologies, particularly in universities with ‘regional campuses’ but have found considerable student resistance to this initiative on the basis that they prefer ‘face-to-face’ teaching, particularly at the Year 1 level. Also, ‘multiple choice’ examinations at the Chemistry 1 level have essentially become the norm to reduce staff time in the marking thereof. The overall impact of a constant overall chemistry student population, a progressively decreasing academic and non-academic staff complement and a decreasing departmental operating budget have combined to produce extreme pressure on the learning and teaching environment of the Chemistry 1 course in Australian universities. In such an environment, it is difficult for departments to address the demonstrated need to protect and enhance the quality of teaching of this course to provide an empowering learning experience for the students involved.

Evans concludes that -

(i) if the trends revealed in this review continue, then by 2020 chemistry as a discipline will have disappeared from Australian universities. Australia will then be an irrelevant backwater of western civilization. Is this really the future for Australia? (p18).

Evans has condemned the enforced downsizing of chemistry departments by progressive budgetary constraints but the RACI has regarded this as an opportunity for a rationalization of resources. In a policy document released in 2001 (RACI, 2001) which emerged from discussions at the 10th Professors and Heads of Departments of Chemistry conference (10th PHODS), it was proposed that mergers of small chemistry departments to attain critical size had merit particularly if these were co-located in the same metropolitan region. Thus, the downsizing chemistry department constraint
becomes manageable if regarded as an opportunity to cooperate rather than duplicate resources.

Osborne (2002) has argued that governments are continuously expecting ‘every part of a university to become cost effective’ and this places a constraint on the system overall and ‘impedes diversity’. In this context, Larkins (2001) has undertaken an interesting assessment of the economic benefits of Australian chemistry degrees and his study has found that -

(on the basis of solely an economic analysis that there are significant direct economic benefits for the government and the individual from the investment being made in higher education. In addition, there are benefits such as quality of life and social factors that are less easily quantifiable in economic terms that result from upgrading of personal skills through higher education.  

(p.18)

It is clear that this type of data which is a scarce commodity, needs to be communicated to the Commonwealth indicating that science degrees are essential components of the ‘Backing Australia’ Ability’ policy and that the number of trained scientists produced in the present decade needs to be substantially increased if the constraint inherent in the present science and technology employment market is to be removed.

5.2.3 Declining student demand for tertiary chemistry

There are considerable data available indicating a progressive decline in student enrolments in secondary school science and tertiary science and, in particular, in tertiary chemistry. The Australian Council of Deans of Science (ACDS) undertook a comprehensive survey of Year 12 enrolments in biology, chemistry, physics and psychology over the decade 1992 – 2002 (Dobson, 2003) which revealed that -

(the statistics suggest a decline in senior school science which must go at least part of the way to explaining the decline in the fortunes of university science (over the same period).  

(p.81)

and that -

(looking more narrowly at students enrolled in science courses courses overall, apart from the biological sciences, the greatest growth has been in non-science/non-Information Technology subjects. For science subjects, the overall interest in mathematics
and physics has been in decline since 1993 and in earth sciences and chemistry, the rot set in 1997. Science students’ engagement with the behavioural sciences has also dropped since 1997. The biological and other sciences both had their best year in 2002. (p.83)

The report concludes that -

(d)eclines in ‘hard’ science at university are strongly correlated with what has happened and is still happening at the secondary level. (p.83)

The declining interest in chemistry at the tertiary level was highlighted by an article in ‘The Australian’ (2001) which indicated a 12% decrease in enrolments in the chemical sciences over the period 1989 – 2000 with a corresponding decrease in mathematics of 13% and physics of 31%. However, over the same period, enrolments in the biological sciences increased by 68% and behavioural sciences by 77%.

The 1995 Australian Nobel laureate Peter Doherty (2003) comments on the declining student interest in science at the tertiary level thus:

Despite their tradition, universities today are struggling to attract students to science. Part of the problem is how science is sold to young people. Everything is presented as though it should be easy and fun. The best are those that realize it should be challenging and tough and it should stretch you. (p.4)

Agreed – but it is necessary to provide science education for the masses and not just those who are likely to excel in it. This is a further constraint imposed upon Year 1 science courses at the tertiary level.

Baker (1998) relates the issue directly to tertiary chemical education:

The problem of the declining trend in the demand for tertiary science could be tackled by analysing our approach to chemical education. There is also a perception with respect to our science that it does not currently serve society positively. (p.8)

Baker ‘blames’ the school chemistry curricula for the overall declining interest in chemistry at the tertiary level and suggests a radical change to teaching chemistry from -

‘tools first, task after’ to ‘application first, tools after’. (p.9)
Here is a supporter of new teaching methodologies in Chemistry 1 and this may well be the way forward to overcome the constraint of declining student interest in tertiary chemistry.

A number of additional concerns were expressed in the interviews with Heads of Chemistry Departments related to the declining demand for tertiary chemistry. One such concern was the wide range of science courses on offer in most Australian universities thereby offering a wide range of choices to incoming students. Thus, the Chemistry Heads believed that chemistry departments are in real danger of being relegated to providing ‘service courses’ for what appear on the surface to be more attractive science courses such as the biological sciences. In this context, Price and Hill (2004) have discussed the constraint of the biological sciences being more popular than the enabling sciences at the tertiary level and a case is made for chemistry having a bright future provided that chemical 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. This will entail improving its public perception, altering and restructuring the curriculum from primary through to and including tertiary chemistry so as to emphasize the multi-disciplinary nature of chemistry and how the individual aspects of chemistry integrate together with other disciplines and highlighting the ultimate outcomes and career opportunities.

However, the Chemistry Heads expressed much concern over the plethora of science courses available at the tertiary level arguing that ‘internal competition’ for an essentially constant student supply is rampant. Prospective students who have elected to take a science course are often confused in their initial course choices. Further, the Chemistry Heads believed that the integrity of some of the ‘newer’ science courses is questionable, if only in terms of the projected employment opportunities. Ethical considerations apply here but the plethora of science courses currently available is competition driven and is perceived to be a real constraint on chemistry, particularly as niche science degrees such as forensic science and nano-science become preferentially popular. The Chemistry Heads believed that chemistry has to follow this trend in order to overcome this constraint and over the last five years many such courses have become available such as medicinal chemistry, environmental chemistry and nano-chemistry – to name but a few. However, these new chemistry courses have placed additional financial constraints on chemistry departments and increased further
the student/staff ratios in an overall climate of reduced resources. Hence, to address the constraint of declining student demand, Chemistry Heads believed that chemistry departments are being forced to ‘teach to the market’ or in more simple terms ‘give the students what they want’, if they are to survive as integral academic units.

The Chemistry Heads also expressed concern over the need to relax the ‘pre-requisites criterion’ for entry into Chemistry 1 in order to attract students and meet pre-set targets. The Chemistry Heads believed that this has and will continue to have an impact on the ‘standard’ of the Chemistry 1 course since in the past, this course has relied on students having a measure of competence in basic chemistry. The Chemistry Heads were concerned that they were forced into accepting students into Chemistry 1 who did not have such competence and that this was another constraint imposed on course content and style of delivery. Since ‘pre-requisites’ in tertiary science have essentially become an historical artefact, in order to overcome this constraint, the Chemistry 1 curriculum has to recognize the wide range of science educational backgrounds of the students involved.

Chemistry Heads also believed that there was an additional constraint imposed on chemistry by the progressive deletion of pre-requisites. It has become increasingly apparent to them that over the last decade, prospective students have insufficient skills in basic mathematics to be able to cope with the Chemistry 1 course. This translates to Chemistry 1 students having an inability to realize and appreciate that ‘science is measurement’ and ‘measurement means manipulation of numbers’. It seems that when this feature is realized it is often a deterrent to the study of chemistry, with the ‘too hard’ label prevailing in the mindset of the student. Chemistry 1 students are therefore relying to an increasing degree on ‘bridging mathematics’ courses to gain some competence with chemistry and Chemistry Heads are aware that work-loads of Chemistry 1 lecturers are increasing since basic mathematical skills have to be taught in the Chemistry 1 course in addition to chemistry.

The Chemistry Heads also believed that ‘lack of a clearly identifiable career pathway’ was related to the declining student demand for chemistry at the tertiary level. There have been many reports on the state of the chemical industry in Australia over the last three decades. Van Santen (2000) has succinctly summed up the situation:

*The core of the Australian chemical industry has collapsed as since the mid-1970’s. Employment opportunities, the number*
of manufacturers, the industry’s contribution to GDP and the number of synthesized products have all declined by at least one-third. The solution is for government to now support industry clusters and to provide a forum for qualified and experienced people to come together to facilitate change and create a (chemical industry) climate conducive to an enduring future. (p.27)

However, Clarke et al. (2003) believe that whereas the chemical industry has to ‘reinvent itself’ to become sustainable and provide increased employment opportunities for graduate chemists, the tertiary sector has to play a role in convincing students of the value-added significance of a chemistry qualification:

Although there are many researchers in our universities who are actively carrying out excellent research programs involving polymers, it is probably fair to say that undergraduate teaching of polymer science in Australian universities has seriously lagged behind. (p.4)

Clarke et al., believe that since the polymer industry is the largest chemical industry in the world and that the most significant development of polymer science in recent years is nanotechnology, here is a unique opportunity for tertiary chemistry departments to teach a ‘new exciting science’ and at the same time show how chemistry plays an integral role in the modern chemical industry.

Quilligan (2002) has offered a further suggestion as to how to address the career path dilemma for graduate chemists by indicating that there are a wide variety of career opportunities available if entrepreneurship is adopted:

Of the numerous career paths to management, it would probably be fair to say that the chemist’s path is generally not one of the more straightforward. It sometimes involves difficult decisions about commitment to science and taking steps into the unknown territories of non-scientific jobs. (p.15)

The solution to the constraint of lack of career opportunities for chemistry graduates relates essentially to an enhanced level of cooperation and collaboration between the chemical industry and the tertiary chemistry sector.
5.2.4 Learning and teaching ideologies

The interviews with the Heads of Chemistry Departments (see Chapter 2) revealed a range of constraints on the tertiary chemistry learning and teaching environment but, paradoxically, they tended to place more blame on ‘external constraints’ which they had little influence on rather than on ‘internal constraints’ which they were able to influence directly. The rationale for the focus of such blame will be examined in this section.

The vexed issue of the status of chemical education in Australia and the lack of acknowledgement and reward for chemical education research in Australian universities was most apparent from these interviews and has been succinctly highlighted by Bucat (2002):

*In Australia, a recognizable chemical education enterprise has been Cinderella to university chemistry departments’ more prestigious fields of endeavour.* (p.12)

The neglect and even contempt for chemical education research in Australian universities is essentially a ‘self-imposed’ constraint on the tertiary chemistry learning and teaching environment but remains an enigma in this context.

Rae (2001) has posed the philosophical question ‘Why do we teach Chemistry?’ He believes that -

*(c)hemistry is part of the canon that everybody should study. All science students should be exposed to the Atkins’ ‘Great Ideas of Chemistry’, and that learning chemistry is like learning a foreign language and a universal one at that, transcending national boundaries and cultures. Chemistry provides students with useful knowledge.* (p.26/7)

It is difficult to disagree with this thesis, the constraint is that potential chemistry students fail to recognize these attributes at the critical stage when they make their decision to enhance their study of chemistry.

There is little doubt that the acute lack of chemical education research in Australian universities is a severe constraint on the tertiary learning and teaching environment. The interviews with Chemistry Department Heads showed that chemical education research does not have similar status and credibility as ‘traditional’ chemistry research and this revelation has been discussed in Chapter 3, particularly in the context that it has been chemical education research and educational theory which
have in large part been responsible for raising the interest level in chemistry internationally. Chemistry Heads tended to blame the lack of vitality of Years 11 and 12 chemistry for the decline in interest in chemistry at the tertiary level and whilst this is true, as has been discussed in Chapter 3, it is only one aspect of the problem.

Another related issue is that in order to protect and sustain the integrity of the Chemistry 1 course, it is widely recognized that the ‘best’ lecturers need to be involved in its delivery. However, most chemistry academics have no formal education qualification and no direct involvement in chemical education research. Whilst most, if not all Australian universities have ‘Academic Skills Units’ which offer guidance in teaching/lecturing methodologies, it is ‘experience’ which primarily nourishes quality chemistry teaching. Hence, it can be argued that the most experienced chemistry lecturers should deliver the Chemistry 1 course, including the Head of Department. It is a paradox and hence a constraint on the course that in general, these academics are either heavily involved in research or in administration and it is well-recognized that the Chemistry 1 course is a ‘time-rich’ commitment. The omnipresent financial constraints on chemistry departments directly affect ‘who’ teaches Chemistry 1. In general, as the interviews with Chemistry Heads revealed, it is the less experienced academics who teach the Chemistry 1 course and thus, again in general, the students are less likely to be exposed to the ‘excitement’ of chemistry, which percolates down from the more experienced research-active chemistry staff. Accentuating the problem is the well-known fact that students in general and particularly at the Year 1 level are uninspired by any teaching methodology other than ‘face-to-face’ and hence chemistry departments are essentially forced to retain the ‘time-intensive’ teaching methodologies.

However, a more severe constraint is that the Chemistry Heads tended to support a rigid adherence to traditional teaching methodologies for the delivery of Chemistry 1 – including the ‘chalk and talk’ approach. In the interviews they admitted that the ‘drift away from chemistry’ was a significant problem and was probably irreversible in the immediate future but they tended to blame the financial constraints on the department rather than attempting to introduce contemporary learning and teaching methodologies in the Chemistry 1 course. The reasons given were that to introduce these teaching methodologies had financial consequences which further exacerbated the acute budgetary constraints of chemistry departments and it was not unequivocally proven that these methodologies added significantly to the learning
outcomes of the course. This, essentially, is an admission that chemistry academics are not aware of the current chemical education research which clearly indicates that such new methodologies such as ‘context-based’ and ‘problem-based’ do enhance the learning capacity of students. This issue has been discussed at length in Chapter 4 relating to the international teaching methodologies adopted for teaching both secondary and tertiary chemistry.

In this context, it is appropriate to emphasize that ‘problem-based learning’ (PBL) has frequently been identified as being the salvation of the Chemistry 1 course but to date, only one chemistry department, Adelaide, has adopted this methodology for Chemistry 1 (Crisp, 1999) and this innovation is discussed in Chapter 6 as a prelude to the design of a new curriculum framework for Chemistry 1. In order to overcome the major learning and teaching constraints currently associated with the Chemistry 1 course, the message of Engel (1997) needs to be headed:

> PBL is not just a method but a way of learning. It is particularly suited to assist students towards mastery in a range of generalised competences and to support effective adult learning in a cognitive and effective aspects of a course in higher education. The quality of the educational environment is equally important if the curriculum is to be implemented by the academic staff who designed it and if it is to be perceived and used by students in the spirit in which it was planned. (p.23)

Further, Little and Sauer (1997) have emphasized that PBL requires a change in the mindset of tertiary teachers and it is apparent that this is difficult to achieve with chemistry academic teachers who traditionally are reluctant to adopt new learning and teaching methodologies. Herein lies a further constraint on the Chemistry 1 course – a realization that change is necessary but a reluctance to enact change. Thus, if PBL is the way forward for the Chemistry 1 course, it is necessary to convert ‘constraint’ into ‘opportunity’ and this involves a significant educational challenge both from a staff and student perspective.

In the past, it is apparent that the Chemistry 1 curriculum has been dominated by ‘traditional ideologies’ since essential questions such as ‘Who is this knowledge for?’ and ‘Who are we educating?’ have not been asked. It is not intuitively obvious that there is a ‘core of knowledge’ inherent in the Chemistry 1 course and yet, in general, this remains as an unquestioned inclusion in the Chemistry 1 curriculum.
across the country. Other questions need to be asked such as ‘Is a university course simply for knowledge acquisition?’ The de-facto scenario is that university chemistry courses have to be vocationally and socially orientated as emphasized by Osborne (2003) to attract and retain students, but as far as chemistry courses are concerned this has not been fully appreciated.

The constraint implied here is the widespread perception of prestige traditionally associated with the Chemistry 1 course and with the university system in general. There is an implied fear that ‘change’ in Chemistry 1 is automatically coupled with a ‘down-grading’ emphasis. The real scenario, as has been discussed in Chapter 3, is that Chemistry 1 need not be reduced in standard if it is based on a new curriculum framework which is inclusive of the ‘social responsibility of science’ factor. There is also the related constraint of ‘protectionism’ of ‘quality’ and ‘standing’ of chemistry in Australian universities which tends to operate as a drag-force impeding change. Status and rank order of topics in the Chemistry 1 curriculum is also an issue. Is ‘risk assessment’ or ‘modelling of chemical phenomena’, for example, of lower rank/status than ‘functional groups’ in organic chemistry? With the traditional ‘old vision’, the answer is ‘yes’ because there is no ‘hard’ core chemistry involved with the former. The new vision says that these topics are important in a well-balanced, vocationally-orientated Chemistry 1 curriculum. These are the ideological constraints on the Chemistry 1 curriculum and there is a need for a paradigm shift from ‘value-free’ knowledge to ‘value-laden’ knowledge. The latter has obvious sociological implications and these are an essential inclusion to humanize chemistry from a student perspective.

Another less obvious constraint revealed by the Chemistry Heads was the ‘forced adoption’ of teaching methodologies based on information technology. It is apparent that most chemistry departments use web-based learning and teaching strategies to varying extents. Thus, the eras of ‘self-paced learning and teaching’ and ‘virtual laboratory teaching’ are well-entrenched. The Chemistry Heads fully appreciated that IT provides a plethora of opportunities for the Chemistry 1 learning and teaching environment, especially in terms of ‘interactive multimedia’, which is an ideal medium for visualization of molecular architecture, chemical reaction mechanisms, energy transitions and transformations and, in particular, chemical modeling. Further, IT-based learning and teaching offers unprecedented opportunities for ‘distance education’, thereby increasing the Chemistry 1 student load and a
consequential strengthening of chemistry operating budgets. However, Chemistry Heads are acutely aware that their operating budgets are totally inadequate to support the necessary IT platforms for such extensive learning and teaching strategies and hence they are totally opposed to faculties devolving an IT budget component to departments, since on such a basis, chemistry departments will be further disadvantaged on the basis of a declining student population. The Chemistry Heads believe that a balance between the traditional and IT learning and teaching methodologies is the best approach for Chemistry 1 in a climate of reducing face-to-face teaching. However, they also believe that the IT learning and teaching revolution cannot be dismissed or ignored but the inherent financial implications of its adoption must be appropriately addressed.

A further constraint on the tertiary system is the enforcement of ‘quality audits’ on universities by the Federal Government as part of their higher education reform package (Nelson, 2002). Osborne (2002) has queried the value of such audits:

Most recently, the marked increase in government interference in university affairs has been exhibited by the imposition of the so-called ‘quality audits’, which are expensive, time-consuming, demoralizing to staff in that they offer criticisms that are largely irrelevant to academic quality and deleterious to the sector as a whole. (p.3)

However, these quality audits cannot be ignored and in this context, the Business Higher Education Round Table (BHERT) has recognized the pressure placed upon the tertiary education sector to improve ‘learning and teaching’ unilaterally (BHERT NEWS, 2003). Indeed, one outcome of the ‘Nelson Higher Education reform package’ is the establishment of a National Institute for Learning and Teaching in Higher Education, and perhaps more significantly, the provision of a Learning and Teaching Performance Fund to (financially) reward those tertiary institutions that best demonstrate excellence in learning and teaching (Nelson, 2003).

In setting the scene for a review of the quality of learning and teaching in Australian universities, Markwell, 2003 argues that –

(t)he urgent need to enhance learning and therefore teaching in Australian universities is increasingly recognised. In the competitive global ‘knowledge economy’, the knowledge and skills of a nation’s people will significantly determine the country’s well-being. This
makes the quality of learning – the acquisition by students of
knowledge, skills and also values – in universities of the utmost
importance for the community as well as for each individual student. (p.1)

However, Markwell also recognizes the institutional constraints implicit in the
learning and teaching reform agenda:

There is near-unanimity on the need for teaching to be focused on
learning outcomes rather than on the teaching process itself, and
especially on engaging each individual student in their own active
learning, including – especially through discussion and debate –
in refining the skills of independent thinking and of clear communication,
which any university education should encourage. (p.1)

The inherent paradigm shift implied here to effect ‘student focused learning’ has
major institutional implications. Markwell concludes that –

(part of the challenge is to think afresh about the content of what
our students learn and what needs to be done to encourage and
assist them to gain that liberal and internationally-focused education,
which, far more than most realize, is necessary, no doubt often as
a prelude to more specialized professional education, to be fully
prepared for careers and for citizenship in this rapidly changing
world. (p.2)

The challenge identified here is singularly relevant to the general debate on the nature
and content of the tertiary ‘Chemistry 1’ course. The interviews with Chemistry
Heads of Departments (see Chapter 2), clearly indicated an urgent need for a
paradigm shift from ‘student focused teaching’ to ‘student focused learning’ – if the
course was to make a major contribution to the sustainability of chemistry as an
enabling science in the 21st century and initiate the training of professional chemists
to meet the demands and challenges of a ‘knowledge-focused’ nation.

With respect to the broad issue of ‘quality’ in tertiary education, O’Donoghue
(2003) poses the inevitable question:

Both teachers and students yearn for quality educational experiences
and outcomes, but what constitutes ‘quality’ and how do we measure it?

(p.28)
To implement a quality strategy in the tertiary sector imposes a further plethora of constraints on the learning and teaching environment as identified by O’Donoghue:

Addressing quality will be difficult because governments, unions, university managements and academic staff have disparate views on many work issues, such as academic freedom, independence, money, resources, workloads, appraisal mechanisms, performance criteria, etc. (p.28)

The interviews with Chemistry Heads indicated that it was a widely held view that the ‘quality’ of teaching in chemistry is directly related to research activity and that even at the Year 1 level, teaching is enhanced and informed by research. It is believed that the essential stimulation for teaching comes from research and it is only possible to ‘teach in context’ if the ‘context’ is related to ‘leading-edge’ research. No research data exist to substantiate these claims and while they may have validity in practice, it is possible to mount a counter argument citing secondary teachers. Excellence in teaching in this area is not connected to research. In short, a heavy research load could be seen as a distraction or teaching seen as a nuisance to be tolerated. This direct linking of ‘quality’ to ‘research’ imposes a range of constraints on the chemistry learning and teaching environment, if only in terms of the consequences of increasing ‘student/staff ratios’ and the concomitant increasing teaching commitments of staff, particularly at the Year 1 level – thereby resulting in a much reduced research commitment. Add to this, the general lack of chemical education research in Australian universities, particularly in the areas of chemistry learning and teaching of chemistry, it is clear that ‘quality’ of tertiary chemistry teaching is at best compromised and at worst, jeopardized.

The issue of how ‘quality’ is measured in universities is queried by Stephenson (2002):

The link between teaching quality and research output is far from axiomatic. If you want to know whether a department is fulfilling its teaching duties, go and talk to the students and lecturers. If you want to know about a scientist’s research capability, go and chat to them at a conference. It is more difficult than crunching numbers but it is infinitely more informative. (p.12)
Stevenson therefore concludes that there is considerable folly in the quantitative assessment of quality in Australian universities.

However, the notion that ‘research’ is essential in the ‘knowledge nation’ and ‘university quality teaching and learning’ debates is affirmed by Larkins (2002):

_Australian universities have a strong tradition of pursuing internationally competitive leading-edge research of high quality over a broad range of disciplines. This tradition must be preserved and enhanced for national social and economic benefit, including underpinning quality teaching and learning programs in higher education institutions._ (p.13)

and:  _A major investment in research must continue to be made inter-alia to ‘buy a seat at the international table of knowledge’ and to have the national expertise to independently assess the potential benefits for Australia of new knowledge produced elsewhere in the world._ (p.13)

and finally:

_Furthermore, an alignment between some of the science, engineering and technology research priorities and humanities and social science research priorities is essential to ensure that science-related work is pursued within a sound ethical, economic and social framework._ (p.13)

This is essentially a plea that the ‘research funding reforms’ inherent in the ‘Backing Australia’s Ability’ initiative recognize that at least 25% of all R&D activities in Australia are conducted in the higher education sector and that these are critically aligned to the quality of the learning and teaching profiles of these institutions. Many additional constraints on the chemistry tertiary teaching and learning environment will eventuate if this is not so recognized.

Hence, there are a wide range of constraints impacting on the tertiary chemistry learning and teaching environment but it appears that many of these can be managed internally within chemistry departments without a major financial impost.

5.2.5 **Negative public image of chemistry**

Perhaps one of the most enduring and perplexing constraints on the tertiary chemistry learning and teaching environment is the poor public image of chemistry.
This has been discussed as an outcome of the interviews with Chemistry Heads (see Chapter 2) and appears to be a national and international phenomenon, as discussed in Chapters 3 and 4 respectively. Despite the significant impact of this phenomenon on the chemistry sustainability scenario, there appears to be few definitive studies undertaken. One such study is that of Stocklmayer and Gilbert (2002):

*It is evident that many individuals have poor images of chemistry and negative attitudes towards it. To some considerable extent, this image has its origins in the school system.*

(p.143)

In broad terms, they argue that there are insufficient books popularizing chemistry, particularly for school children. Such books as do exist, such as Selinger’s ‘Chemistry in the Marketplace’ – require at least knowledge of high school chemistry for full appreciation. Further, many books that popularize science attribute important chemical discoveries and chemical ideas to other science disciplines, particularly biology, so that the chemical significance is lost on the reader:

*It would seem that chemists need to reassert the place of their subject in scientific advances. Genetics is, after all, chemistry. The deep interpretation of specific biological phenomena in terms of genetics is only just beginning in earnest.*

(p.149)

They also examined a number of leading international newspapers and magazines and found that -

*(c)hemistry is always present in some form in newspapers and magazines, but only in a heavily disguised form. In mainstream television however, chemistry often features in news items or current affairs programs about issues of public concern. Perhaps the most confusing presentation of chemistry to the general public occurs through commercial presentations on television. It does seem that, despite the science education that people receive, their understanding of scientific aspects of everyday television advertisements is limited. The chemistry of advertisements encourages the public to feel as if they know and understand what is being said, by presenting them with situations that seem interesting, while in practice further distancing them from the underlying science. Much work by chemists, communicators, and indeed those concerned with morality in everyday life, will be*
needed if chemistry is to be rescued from the deep pit of public skepticism to which advertising may consign it. (p.152/3)

Thus, the issue of the public image and perception of chemistry is a serious constraint on its success as an enabling science and inevitably, it will take considerable time and effort to remedy this problem. Stocklmayer and Gilbert suggest that the core of the necessary remedial action is that -

(i)formal chemical education must be intrinsically entertaining, such that the public must want to participate. For real promotion of personal awareness of chemistry, personal relevance must be clear. Interactive processes must be employed. The public will engage seriously with complex scientific issues when their lives are deeply affected. (p.159/60)

The ultimate analogy inherent in this remedial action is that students will learn chemistry effectively when mechanisms are found to effectively engage them in the learning process and in this respect, chemistry students and the general public have much in common in terms of empowerment via scientific literacy.

5.2.6 Legislative constraints

Other, less obvious constraints on the Chemistry 1 course were revealed from the interviews with Chemistry Heads. Occupational Health and Safety (OH&S) legislation is having an increasing impact on chemistry laboratory sessions in that chemicals have to be classified and stored according to their toxicity levels and chemical usage in the laboratory has to be accompanied by a ‘risk assessment’ process. This imposes several constraints. The former requirement imposes additional workloads on laboratory technical staff and the latter imposes additional workloads on academic teaching staff and overall, constraints are imposed on the type of chemicals which can be used in laboratory sessions. At the Year 1 level, this usually means that only the least toxic chemicals can be used in laboratory exercises with consequential minimal risk to students. This constraint further promotes a reduction in number of laboratory exercises undertaken in the Chemistry 1 course. However, the Chemistry Heads recognized the importance and significance of laboratory exercises in chemistry – since chemistry is inherently an ‘experimental science’ and laboratory work is known from student feedback surveys to be a major stimulant of student interest in chemistry and effectively compliments theoretical concepts. The current stringent OH&S regulations have maximum impact on the use of organic chemicals in
the undergraduate laboratory since most, if not all of these are categorized as ‘toxic’. Hence, Chemistry 1 laboratory exercises involve a diminishing number of organic chemistry experiments and a proportionally increasing number of physical chemistry experiments which are subject to less stringent OH&S regulations. However, students relate less enthusiastically to these types of experiments because of the (usually) complex mathematical calculations involved. The Chemistry Heads recognized that a range of ‘benign’ chemistry laboratory experiments need to be devised for the Chemistry 1 course and that there is a very real possibility that the conventional ‘hands-on’ laboratory exercises in organic chemistry will have to be replaced by ‘virtual’ laboratory exercises. They agree that this is a retrograde step but is being driven by intransigent OH&S regulations and legislation.

5.3 CONCLUSION

The six groups of constraints on the Chemistry 1 learning and teaching environment which have been identified in this chapter, are now classified in order of manageability and are listed in Table 5.1 along with brief recommendations for remedial action. The order of manageability given is subsequently rationalized.

Table 5.1 A summary of ‘constraints’ and suggested ‘remedial actions’.

<table>
<thead>
<tr>
<th>CONSTRAINTS</th>
<th>REMEDIAL ACTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Politically imposed</td>
<td><strong>Not presently manageable.</strong></td>
</tr>
<tr>
<td>Present triennial Commonwealth funding model for universities does not allow long-term planning.</td>
<td>Use the political influence of FASTS, AAS and RACI to lobby the Commonwealth for longer term university funding, especially for tertiary science education and for scientific research.</td>
</tr>
<tr>
<td>Increase in HECS fees is likely to have a negative impact on university enrolments.</td>
<td>Chemistry departments must find ways to manage increases in HECS fees by enhancing learning and teaching, particularly at the Year 1 level.</td>
</tr>
<tr>
<td>Budgetary</td>
<td><strong>Not presently manageable because these constraints are directly tied to Commonwealth funding of Universities.</strong></td>
</tr>
<tr>
<td>Chemistry department operating budgets are tied to student load.</td>
<td>Chemistry departments must find ways to increase student load by offering niche degrees which are</td>
</tr>
</tbody>
</table>

178
- Chemistry emphasis and status in science faculties is declining.
- Chemistry departments are not being funded in proportion to their central role in science faculties.

### Declining student demand

- Students are not attracted to chemistry at the secondary level.
- The shortage of school science teachers means that school chemistry is not always taught by teachers with a chemistry qualification.

<table>
<thead>
<tr>
<th>Associated with significant chemistry content and attracting full fee-paying international students.</th>
</tr>
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<tbody>
<tr>
<td>Chemistry must expand its traditional boundaries to embrace ‘new’ sciences and teach to these boundaries. Chemistry must not fragment and be subsumed by other sciences such as biochemistry. Science faculties must maintain a holistic view of chemistry.</td>
</tr>
<tr>
<td>Chemistry departments must lobby university senior managements to recognize that a ‘science and technology literate university’ equates to a chemistry, physics, mathematics and engineering foundation.</td>
</tr>
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<table>
<thead>
<tr>
<th>Partially manageable.</th>
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<tbody>
<tr>
<td>Chemistry department must address the symptoms such as the attraction of the ‘soft sciences’, business/commerce, computer science and creative arts by making chemistry more exciting and challenging at the Year 1 level. It is also necessary to address the perception of science at school certificate level as ‘low status’ and ‘low reward’ by revealing (with the assistance of the chemical industry) the wide range of rewarding career opportunities available to trained chemists. It is also necessary to address the major school view of chemistry that it is ‘teacher centred and content - focused’, personally irrelevant and difficult by emphasizing ‘personal connections’ of chemistry and exciting teaching at both the secondary and tertiary levels.</td>
</tr>
<tr>
<td>The RACI must embrace school chemistry teachers by offering them Associate Membership, possibly at a reduced rate and also, in conjunction with tertiary</td>
</tr>
</tbody>
</table>
• Chemistry is seen as ‘dull’ and ‘boring’.

• Chemistry departments, provide professional development opportunities for chemistry teachers.

• Chemistry departments must continue to be imaginative by introducing specialist niche courses to offset the attraction of biotechnology courses. The Chemistry 1 curriculum needs restructuring to change its image to an exciting, socially-responsible foundation chemistry course. Chemistry departments need to support the initiatives of the RACI to popularize chemistry in the public domain. Chemistry departments need to interact more effectively with the secondary school network, particularly at the school certificate level.

Learning and teaching ideologies

• There is a disconnection between senior science pedagogy, curricula and learning styles versus student interests.

• The chemical education research profile in Australian universities is low by international standards.

• The Chemistry 1 curriculum needs to be reformed.

Manageable if traditional ideologies are abandoned.

• Change to a ‘student first’/‘content second’ pedagogy at the tertiary level with the introduction of contemporary learning and teaching methodologies in the Chemistry 1 course and an assurance of a ‘student-focused’ learning environment.

• Chemistry departments must recognize the intrinsic value of chemical education research in empowering chemistry teaching at all levels and particularly at the Year 1 level.

• A new curriculum framework for the Chemistry 1 course must be designed which accommodates the wide range of previous science and mathematics knowledge of students, the fact that most students will not continue with chemistry studies, the need to portray chemistry as the central science, its relationship to other sciences, particularly the biological sciences and its ‘technology enabling’ features. It
<table>
<thead>
<tr>
<th>Niche chemistry degrees are too few in number.</th>
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<tbody>
<tr>
<td>is necessary to show that chemistry is above all – a socially-responsible science. Further, chemistry departments need to appreciate that retention in tertiary chemistry is highly dependent on teaching quality at the Year 1 level.</td>
</tr>
<tr>
<td>The RACI needs to embrace niche chemistry degrees and accredit them appropriately.</td>
</tr>
</tbody>
</table>

**Negative public image of chemistry**
- The image of chemistry is established at the senior school level.
- Benefits of chemistry to the public are largely invisible.

**Progressively manageable.**
- Chemistry departments need to interact with the secondary school sector to overcome the difficulty of science students being able to visualize a chemist and ‘what he/she does’. Students are able to visualize a biologist or archaeologist since they frequently see ‘what they do’ on TV. Hence, students cannot visualize themselves as chemists. Students need to see a personal connection between themselves and chemistry to be able to visualize themselves as chemists.
- The RACI needs to more rigorously lobby the media on such benefits – ranging from the ‘simple’ to the ‘complex’. Chemistry departments need to interact with the media seeking publicity on ‘leading-edge’ chemistry achievements with directly benefit society. They need to support the RACI in its efforts to improve the image of chemistry in Australia. University ‘Open Days’ need to be used to advantage to convey the excitement of chemistry to the public.

**Legislative**
- OH&S legislative compliance restricts scope of undergraduate chemistry experiments.

Manageable. Chemistry departments are compelled by legislation to operate safely with respect to the handling and storage of chemicals.
- With respect to guaranteeing safe laboratory practices, chemistry departments need to be more
• OH&S regulations stifle exciting experimental chemistry.

• Imaginative and pro-active in progressively introducing ‘green chemistry’ experiments into laboratory sessions, particularly at the Year 1 level. This has the additional benefit of improving the image of chemistry from a student perspective.

• Convert ‘constraint’ into ‘opportunity’. Chemistry departments must make clear to other science departments that only chemists can guarantee the teaching of experimental chemistry to comply with existing OH&S regulations governing the use of chemicals. Health and Biological science departments do not have the facilities or expertise to effect this. Thus, chemistry departments mount a strong case for teaching all chemistry courses in the faculty, thereby sustaining their operating budgets.

The order of manageability of these constraints is essentially self-evident. If the constraints are seen by chemistry departments as opportunities, then all will become manageable over time. It is essential that those which have been labelled as ‘partially manageable’, such as ‘declining student demand’ are addressed as a priority since it is believed that these have the greatest impact on resolving the present chemistry crisis in Australia. Also, it is essential that the learning and teaching constraints are overcome expeditiously in order to sustain the viability of tertiary chemistry and it is believed that a restructuring of the Chemistry 1 course will significantly remedy many of the image constraints of chemistry and also address the lack of enjoyment of chemistry by science students. If the chemistry crisis in Australia is to be overcome, then all the constraints identified have to be addressed with vigour, imagination and determination by the professional chemistry community working collectively for the common good.
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CHAPTER 6
A PRELIMINARY CURRICULUM FRAMEWORK FOR A RESTRUCTURED CHEMISTRY 1 COURSE

6.1 INTRODUCTION

The purpose of this chapter is to examine the necessary curriculum theory for a reform framework of a tertiary Year 1 chemistry course, generically referred to as the ‘Chemistry 1 course’. The preliminary framework proposed is based on three premises – the Atkins fundamental proposal that ‘chemistry is based on a few simple ideas’, the curriculum theory proposed by Lawton – his so-called nine cultural sub-systems and the ‘social responsibility of science’ philosophy, proposed by Fensham. The Atkins proposal has been discussed at length in Chapter 4 and the Fensham proposal has been discussed in Chapter 3. The Lawton curriculum theory principles are first introduced in this chapter and these three premises combined form the theoretical basis of the proposed new curriculum framework for the Chemistry 1 course. The proposed Chemistry 1 curriculum framework is published in a national chemistry journal and feedback comment is solicited from the readership of this journal so as to provide a quantitative estimate of the intrinsic value of such a curriculum in terms of addressing, at least in part, the overall decline of interest in chemistry in Australia.

The scope of this chapter is to present a preliminary curriculum framework for a new Chemistry 1 course and to publish this as a ‘test exemplar’. The full framework will be presented in Chapter 7 after the comments received on the preliminary framework have been analysed and noted. From an intensive review of the international chemical education literature, as presented in Chapter 4, the scope of this chapter includes a critical short review of the very few reforms of the Chemistry 1 curriculum which have been undertaken to date since this adds significant impetus and urgency to the present project. Further, the 1999 interviews with Heads of Chemistry Departments clearly revealed the need for a reformed Chemistry 1 curriculum but also lethargy towards undertaking this task due to its perceived complexity and magnitude, given the plethora of constraints involved. The scope of
this chapter together with that of chapters 7 and 8 essentially answers the core
questions of this thesis.

The criticisms and comments on the proposed curriculum framework outline
for the Chemistry 1 course should provide a useful measure of the intensity of the
current reaction to reform among the chemistry fraternity and, in particular, the
current reaction to a ‘reformist agenda’. Also, it should be possible to obtain the views
of chemists about matching educational theory to curriculum content as applied to
Chemistry 1. Based on anecdotal evidence and a clear lack of status of chemical
education within the chemistry academic community (as discussed in Chapter 3), it is
recognized that the traditionalist chemistry educational climate is somewhat resistant
of ‘educational theorists’ and reluctant to call for their assistance in addressing the
identified problems with the current Chemistry 1 course. The irony to be tested in this
chapter is that from the present research the author believes that it is only via
‘educational theory’ coupled with an injection of the ‘social responsibility of
chemistry’, that a viable solution can be found to the overall problem with the current
Chemistry 1 course in Australian universities.

6.2 A PRELIMINARY CHEMISTRY 1 COURSE CURRICULUM FRAMEWORK

The fundamental rationale for proposing a new curriculum framework for the
Australian tertiary Chemistry 1 course is to attract more students into tertiary
chemistry study and retaining them as ‘chemistry majors’. It is thus a ‘turning
students onto chemistry’ initiative and is intended to strengthen the enabling sciences
in Australian and support the ‘knowledge nation’ concept. The proposed new
curriculum framework for the Chemistry 1 course embraces the principles of the
‘social responsibility of science’ (Cross and Price, 1992) and ‘science for all’ (Cross
and Fensham, 2000) principles (see Chapter 3), which have been so poignantly
neglected in both past and present chemistry curricula. This is an ambitious
assignment but is widely believed to be an essential element in reversing the present
declining status of chemistry in Australia.
6.2.1 Some theoretical principles of science education

Almost half a century ago, Schwab (1958) argued that ‘science teaching should nurture themes that characterize science as a way of knowing’. Erduran and Scerri (2002) have commented that –

(s)everal decades later, overwhelming evidence suggests that science education is not doing enough to align science teaching with contemporary perspectives in philosophy of science. (p.7)

Schwab (1964) argues that –

(s)cience teaching continues to reinforce a ‘rhetoric of conclusions’, a tradition that perpetuates the learning of conceptual outcomes while neglecting the learning of strategies that enable knowledge growth in different fields of scientific enquiry. (p.31)

Brush (1996) has asserted that –

(c)hemistry relies on classification schemes such as chemical models which explain more the qualitative aspects of matter. (p.169)

Traditional educational research that empowers the teaching of chemistry places an emphasis on problem-based learning, concept-based learning and learning of science-process skills. These methodologies have been discussed in depth in Chapters 3 and 4 and will be discussed further in this chapter. Erduran and Scerri, 2002, believe that a fourth dimension should be added to the empowerment of chemistry teaching list – the application of themes from the philosophy of chemistry involving the reduction, explanations, laws and supervenience that form the foundation of chemistry philosophy.

Many educational theorists have successfully argued that ‘science needs to be connected to its social and historical roots (Duschl, Hamilton and Grady, 1992, Hewson and Thorley, 1989, Mathews 1994 and Shortland and Warwick, 1989) and Erduran and Scerri (2002) have concluded that –

(s)ince science teaching has traditionally embraced little or no reference to the cultural, personal and historical contexts in which science occurs, learners of science do not develop an appreciation of science as a human endeavour. History and philosophy of science is thus advocated as an instrument for humanizing science and a catalyst for motivating students’ interest in science. (p.9)
However, from the present review of the international chemical education literature, as discussed in Chapter 4, it is apparent that over at least the last two decades, the overlap and effective interaction of chemical education research with history and philosophy of chemical principles and applications has been minimal and it can be argued that such a situation is a reflection of chemists’ marginal interest in the historical and philosophical dimensions of their science. This is a significant factor impeding change in chemistry course curricula generally but this feature needs to be included in the present proposals for a new Chemistry 1 curriculum framework.

One of the key concepts which have driven change in chemistry course curricula in the past is ‘relevance’ and it is difficult to argue against making chemistry ‘relevant’. It is argued that ‘students like to relate chemical principles to everyday things’ but often it is difficult to quantify ‘relevance’ in chemistry courses and particularly in the Chemistry 1 course. It is apparent from the 1999 interview series with Heads of Chemistry Departments, that ‘relevance’ has been the most discernible trend penetrating the teaching of Chemistry 1 and that context-based learning is evident in a variety of interpretations, including ‘technological’, ‘industrial’, ‘environmental’, ‘economic’, but rarely, it would appear, in a ‘social’ context. Motivation of students has been the strongest driving force in the development of ‘relevant’ curriculum content for Chemistry 1. Science education research has shown that ‘relevance’ is linked to the ‘scientific literacy’ of society – loosely defined as ‘people being able to make sense of some of the many ways in which science impinges on their everyday lives.’(American Association for the Advancement of Science – AAAS, 1989). This is certainly an ethic which needs to be rigorously incorporated in the Chemistry 1 course curriculum.

In Appendix 5, it is noted that the Salters’ Chemistry Course for secondary students is a context-based science curriculum, which is widely used in secondary schools in the UK and Europe and has been applauded as a means of encouraging students to study chemistry beyond the secondary level (see Chapter 3). It is argued that learner motivation is the strongest driving force in promoting this outcome. Perhaps, more importantly, the Salters’ course is designed both for students who will take their study of chemistry no further than the end of compulsory schooling at age 16 (the so-called ‘generalists’)) and for those who will continue chemistry studies in pre-university courses (the ‘specialists’). Thus, a context-based pre-tertiary chemistry course can significantly address a major problem with the present Australian
Chemistry 1 course that it has to relate to both the ‘generalists’ and the ‘specialists’ emerging from the secondary domain and those who have had no previous exposure to chemistry. In this context, Bennett and Holman (2002) support the ‘context-based’ approach:

*A context-based approach makes it possible to develop a curriculum whose content is closely related to the needs of the students concerned, as determined by the contexts in which they will lead their lives. A perceived benefit of a context-based approach is thus that it is a good way, perhaps the only way, to develop a curriculum for scientific literacy.*

However, because of the range of abilities and chemical education backgrounds of Chemistry 1 students, a major challenge is to design a curriculum for this course that meets the needs of all the students – the generalists and the specialists. Bennett and Holman (2002) have offered the following constructive advice:

*The key design decision is to place the needs of the generalists first and to design an integrated (chemistry) curriculum for scientific literacy from the bottom up. This constitutes the compulsory core for all students and can then be supplemented with specific chemistry topics to meet the needs of those who intend future specialist study.*

In an essay on ‘Models and Modelling in Chemical Education, Justí and Gilbert (2002) suggest that –

*(a)* chemistry is concerned with the properties and transformations of materials, chemists are essentially modellers of the substances that constitute such materials and of their transformations. Chemists model both the phenomena they observe and the ideas with which they try to explain such phenomena at both the macroscopic and microscopic levels. Thus, chemical knowledge about a range of phenomena is produced and communicated with the use of several models, which evolve and are changed as the field of enquiry advances.

The Heads of Chemistry Departments in the 1999 interview series strongly advocated the use of ‘chemical modelling’ in the teaching of the Chemistry 1 course simply because (computational) models and modelling have been comprehensively
entrenched in chemical research and these are essential tools for investigating known and new substances and their transformations and are vital for probing the properties and potential uses of new chemicals – one of the most important areas of chemical research. It is thus apparent that ‘chemical modelling’ has to be an essential ingredient in the proposed re-structured Chemistry 1 course as a pre-established element of the active learning process.

In this context, Taber (1999) has argued that ‘understanding the nature and significance of chemistry students’ alternative frameworks is a way of making teaching (of chemistry) more effective and the learning of chemistry less frustrating to students. Students bring to their study a range of ideas and explanations that may or may not be consistent with established scientific explanations for particular chemical phenomena. Tronson and Ross, 2004 have modelled a range of teaching and learning strategies for Chemistry 1 and have quoted the anonymous prophesy that –

(t)he average teacher tells; the good teacher explains; the superior teacher models and the great teacher inspires. (p.11)

Whilst both of these papers advocate ‘chemical modelling’ as an effective teaching tool in Chemistry 1, it must be used with caution, especially since students can have a range of different perceptions of the significance of the model used and its inherent connection with the chosen chemical concept.

6.2.2 Recent restructuring proposals for the Chemistry 1 course

Subsequent to a comprehensive review of the national and international chemical education literature, as discussed in Chapters 3 and 4, respectively, it is surprising to discover that very few curriculum reviews of the traditional Chemistry 1 course have been undertaken, let alone new curriculum frameworks proposed. Three previous restructures are sufficiently significant to warrant special discussion. Crisp (1999) realized that –

(n)ew technologies, external expectations and the dynamic nature of chemistry all shape the learning and teaching environments in our universities. (p.6)

The University of Adelaide Chemistry Department undertook a comprehensive review of ‘Chemistry 1’ in 1999 subsequent to a realization that ‘both staff and students needed to be aware of new paradigms of learning and teaching and that changes in pedagogy would necessitate changes in the presentation format of subjects as well as their method of assessment.’ This review was unique in Australia at that
time in terms of its breadth, depth and impact and no similar comprehensive review of Chemistry 1 has been reported since. Crisp (1999) identified one of the core misconceptions associated with the Chemistry 1 course:

At the simplest level, the idea of a flexible learning and teaching environment has been interpreted as digitizing all teaching material and suggesting to students that they now have full control over their own learning. The successful establishment of such an environment will require a cultural change within the university for both staff and students. (p.7)

Crisp (1999) also identifies the critical role of the student in the learning process that -

(i)n addition to the factual information that students must assimilate, chemical educators need to provide students with a framework within which the information can be used in a constructive manner. Staff need to encourage learning strategies that will be of benefit to lifelong education. (p.7)

Some crucial advice is given on curriculum design of Chemistry 1:

Defining the aims for a subject is crucial to the development of the syllabus. The aims for Level 1Chemistry were defined as: to encourage critical thinking, to enhance problem-solving ability, to gain an appreciation of scientific methodology, to encourage professionalism, to provide a basis for further study in chemistry and other sciences and to provide students with a career path in chemistry or other science-related area. (p.7)

And:

Since students come into university with a wide variety of experiences in terms of chemical background, we have structured the initial section (of the course) so that the content relies less on a background knowledge of chemistry and more on a desire to think laterally. We have departed from the formalism that emphasized that students could not understand new or advanced topics before having a thorough understanding of all previous basic concepts. The subject matter is more contextual, an approach familiar to recent school leavers. The various sections (of the course) are now interrelated with frequent revision of key concepts.
Isolated facts or information that is not used elsewhere in the course have been left to later years, as needed. Chemistry 1 is now more cohesive and seamless.  

Crisp (1999) concludes:

Our experience has been that with proper planning, genuine syllabus reviews and a reflective use of computer technologies, staff can provide a more flexible learning and teaching environment and significantly enhance the learning experience of participating students.

In a separate paper, Crisp (2002) gives a seven-point check list for a Chemistry 1 curriculum framework design, which is worth citing here:

Establish identifiable goals that are stated and reinforced with the students; distinguish between ‘essential’ and ‘optional’ material; reinforce the core concepts and provide clear models for concepts; provide a framework for the content; remove anything that is not used later in the subject; provide opportunities for collaboration and ‘redeemable assessment’; do not teach from the textbook and keep it simple.

Butcher et al. (2003) in the USA have designed a new Chemistry 1 course which they have titled ‘Sparky IntroChem’ which they believe shifts the focus of the classroom from the teacher to the student:

With emphasis on student orientated learning, we have introduced approaches in our IntroChem course designed to improve student learning in mathematical problem-solving skills, understanding and using concepts, scientific reasoning and development of positive attitudes towards science. The goal has been to develop an engaging student-centred course.

‘IntroChem’ consists of a number of innovative modules, laboratory experiments and workshop materials. The modules focus on issues of societal importance, especially of ‘local’ importance. The laboratory experiments are designed to help students develop scientific reasoning skills and it was found that by replacing some in-class examinations with projects helps students to discover the relevance of chemistry.

Novak (2001) in Singapore has described a new ‘non-traditional’ chemistry course which aims to broaden the educational background of chemistry graduates:
As this century unfolds, one can expect that unprecedented advances will take place in all the fields of modern science and technology, including chemistry. Ironically however, the gap between the widespread use of scientific discoveries and the understanding of the capability of science and its limitations, its operating principles and its social context grows ever wider. The scientific literacy of a great majority of the population does not keep pace with scientific progress. (p.32)

Novak describes in outline the curriculum framework of a ‘chemistry course’, which could be adapted to a curriculum framework for the Chemistry 1 course and consisting of the elements of the philosophical and methodological aspects of chemistry, the sociological aspects of chemistry and the historical aspects of chemistry. The proposed framework is essentially an acknowledgement of the essential ingredients for a chemistry curriculum proposed by Erduran and Scerri (2002) with a determined emphasis on the history and philosophy of chemistry. In this respect, it is aligned with modern educational theory as applied to the learning of chemistry.

These three examples of a restructured Chemistry 1 course all have at least one theme in common – development of a student-based learning course and all are very significantly different in structure from that of the traditional course. New teaching methodologies such as context-based and problem-based learning are emphasized together with an emphasis on the relevance of chemistry, particularly in a sociological context. Achievement of scientific literacy is an important aim of the courses described along with students obtaining enjoyment and motivation from the course. These authors all believe that ‘Chemistry 1’ is a crucial course for the development of a wide range of skills which participating students can carry with them in ‘life long learning’.

6.2.3 Some new proposals for restructuring the Chemistry 1 course

In structuring a preliminary new curriculum framework for Chemistry 1, the author was significantly assisted by discussions of this issue with a world leader in science education – Professor Peter Fensham of Monash University in 2001/2. Discussions with Fensham (in 2001) focused on pedagogical constraints apparent in Australian academic chemistry particularly in terms of its failure to ‘keep up with the times’ and its failure to take advantage of the disappearing boundaries of chemistry in
a world increasingly dependent of scientific and technological knowledge. Essentially, the ‘position of science’ has changed dramatically but the Chemistry 1 content is fundamentally little changed from the 1960’s. For example, it is still widely believed that the organic chemistry section of the course should be based on ‘functional groups’ as a means of grouping organic compounds into families and characterizing the reactions of organic compounds. However, the main interest of students in organic chemistry is related to ‘biochemistry’ which does not depend exclusively on functional groups. Further, the multiple opportunities for modelling chemical processes have not been taken up in the teaching of Chemistry 1. Modelling of real chemical processes, such as those carried out in industry can introduce additional concepts such as ‘economics’ and cost/benefit analyses as applied to existing and potential production of new chemicals. Modelling is widely used in other sciences such as biology, environmental science, medicinal chemistry and polymer chemistry – to name a few but it does not appear to have been fully exploited in the advancement of chemistry. Further, in terms of Chemistry 1, it is necessary to ‘teach to the market’. There are two broad groups of students in Chemistry 1 – the minority who will continue to study chemistry and the majority who will not. Essentially, a ‘double-wedge’ curriculum framework needs to be adopted whereby the necessary academic knowledge is linked directly to vocational attributes, not only of chemistry but also of science in general. Such a framework is inclusive of the ‘interest maintenance’ and ‘chemistry social responsibility’ factors, which have been so obviously lacking in the traditional Chemistry 1 course. The vocational wedge should also indicate the wide variety of vocational opportunities available for graduate chemists and how chemistry enables and bridges other sciences. It should also demystify chemistry in terms of a mass of theoretical concepts with little obvious practical application into a vigorous, dynamic science at the frontiers of knowledge and (consequential) social reform. The ultimate aim of the Chemistry 1 curriculum should be to present chemistry as an attractive, relevant and rigorous science of profound economic and social consequences.

The Fensham discussions of 2002 focused on taking the proactive approach and designing a preliminary curriculum framework for the Chemistry 1 course, which has as its main aim, the engagement of students with chemistry. The new framework should recognize the wide range of imperatives for reform as revealed in this research project and should also include the ideas discussed in 2001. The proposed framework
Roger Cross endorsed publishing a preliminary Chemistry 1 curriculum framework to test the strength of the reform agenda, but also, and most critically, proposed that the framework should include the empowering features of ‘educational theory’ – in particular, the Lawson structure of a curriculum template based upon ‘8 systems’. It was these discussions which led to a presentation titled ‘The imperatives for reform of first-year university chemistry: Educational Theory to the rescue’ (Hill and Cross, 2002) at the RACI – Chemical Education Conference, 2002, which is included in Appendix 4. It was the combined discussions of Fensham and Cross (2001/2 and 2003) which led to the publication of a preliminary Chemistry 1 curriculum framework in ‘Chemistry in Australia’ in 2003 – ‘The Chemistry 1 course: a critical element for change’ (Hill, 2003) – which is also included in Appendix 4.

6.2.4 A preliminary curriculum framework for the Chemistry 1 course

The many and diverse drivers for change in approach and attitude towards chemical education in Australian universities have been comprehensively reviewed and summarized in Chapters 3 and 4 and now it is timely to structure the essential changes necessary to revive and invigorate the Chemistry 1 course. This has never been assumed by the chemistry fraternity to be a simple task and it is one which has not been rigorously attempted in the past due to its complexity. Such complexity is proportional to the magnitude of the necessary paradigm shift in ‘attitude’ towards change in the Chemistry 1 course. University chemistry has been taught in the traditional way for so long with the belief that even at the Year 1 level, the traditional chemistry lecture is empowering students to follow a career involving at least a substantial component of what might be called ‘hard-core chemistry’. However, the demographic distribution of students enrolled in Chemistry 1 has changed very dramatically over the last two decades and at the present time, only a small fraction of those enrolled in chemistry will end up as professional chemists and hence the traditional way of teaching Chemistry 1 is inappropriate. Hence, there has to be a re-conceptualization of university chemistry such that a student-focused learning environment is achieved.
Further, the envisaged reform process for Chemistry 1 has to recognize that chemistry is an enabling science and as such, is a major contributor to scientific literacy. The ‘new age’ Chemistry 1 course must therefore contain a substantial range of enrichment factors over and above basic chemical knowledge to provide the required base level of scientific literacy. This is most important for those Chemistry 1 students who will take only one unit of chemistry in their entire undergraduate science course. Of the many enrichment factors must be the realization that chemistry, like all science, has a human dimension and is advanced by human intervention and human ideas. Other factors in this context are the social responsibility of chemistry and its empowering force in affecting social change and inducing the ‘knowledge nation’ cause.

It appears inevitable that Chemistry 1 has to be associated with a ‘core of chemical knowledge’ which essentially is a basic tool kit of essential chemical concepts. However, such a core of knowledge has to be presented in a style that students can relate to, even if their previously acquired scientific knowledge is meagre or non-existent. An appropriate learning environment for Chemistry 1 has to be created which purposely avoids rote learning. It also appears inevitable that the Chemistry 1 reform process has to acknowledge the increasing proportion of students whose numeracy skills are limited. Therefore some topics in Chemistry 1, especially in analytical and physical chemistry, have to be presented in essentially a ‘mathematics free’ format unless the necessary mathematics skills are addressed in situ.

The Chemistry 1 reform process is unlikely to be dominated by the extensive or exclusive use of information technology. IT is however, likely to be one of several tools which enable Chemistry 1 to be delivered to students in a variety of formats which they can relate to and enjoy largely because of its interactive, self-paced features. Certainly the present ‘IT revolution’ is already a major catalyst enforcing a directed drift away from the traditional teaching methodologies, a drift which cannot be ignored. However, due to inherent levels of conservatism in the tertiary chemistry domain, new methodologies and new technologies are adopted which caution and hence the inclusion of IT into Chemistry 1 is likely to be a cautious and considered progression.

Overall, the necessary Chemistry 1 reform process intuitively involves a new vision both in terms of curriculum framework and teaching methodologies along with
preferential recognition and inclusion of creative teaching methodologies. It should be noted at this point that while teaching methodology and curriculum are closely connected, the scope of this study does not enable the author to do more than indicate the importance of the teaching methodologies to be used.

The reform process considered here is based on three premises, the first of which is the Atkins proposal that ‘chemistry is made up of a few simple ideas’. His so-called ‘diet of chemistry’ has been widely publicized within the chemical education fraternity (Berressern, 2003) and comprises nine ‘ingredients’:

- Matter consists of atoms: atomic structure accounts for periodicity: bonds form by electron-pair sharing: shape is of paramount importance: there are residual forces between molecules: energy is conserved: energy and matter tend to disperse: there are barriers to reaction and there are only four types of reaction.

Although these ‘ingredients’ are inclusive of the ‘language of chemistry’, they provide a crucial insight into the simplicity of chemistry and a vision for a chemistry learning and teaching plan for Chemistry 1. This is perhaps the most profound indicator of the way forward in chemistry course design and eclipses the debate on the ‘core of chemical knowledge’ which Chemistry Heads of Department believe is an essential ingredient in the Chemistry 1 curriculum (see Chapter 2).

The second premise on which the proposed Chemistry 1 curriculum framework is based is Lawton’s education theory (Lawton, 1989). This is a complex but visionary theory made up of nine ‘elements’. Lawton has indicated that these ‘elements’ are the essential foundation on which knowledge is communicated from one generation to another. These elements are ‘social-political’, ‘economic’, ‘communication’, ‘rationality’, ‘technology’, ‘morality’, ‘belief’, ‘aesthetics’ and ‘maturation’. Simply interpreted, the Lawton elements are essentially a definition of the dimensions of knowledge and are the carriers for its transmission. Thus, they are adopted here as the dimensions of chemical knowledge and the carriers of its transmission at the foundation tertiary level. In this context, a brief discussion of the Lawton elements follows with each described in chemical paradigms.

Although Lawton does not place his ‘elements’ in rank order, previous Chapters 2, 3, 4 and 5 have revealed that the ‘social’ aspect of chemical knowledge is perhaps the major force driving change in chemical education and is aligned with the
Fensham ‘science for all’ philosophy which is the foundation of scientific literacy. If the ‘social’ and ‘political’ dimensions are linked together, then ‘national development’ and ‘knowledge nation’ political ambitions follow. However, the ‘social-political element’ also includes recognition of the types of chemical knowledge that enhance or hinder social and physical development and the ways that chemical knowledge is negotiated in the public domain together with recognition that chemical discoveries need to have an established knowledge aim and social relevance. Lawton’s socio-political system is fundamentally concerned with ‘power structures’ and ‘authority’. In relating this interpretation to a scientific culture, the latter reflects wider society in the range and number of its hierarchical organizations and associations. Organisational and authority structures exist within science in three main contexts: within research and teaching in universities, as government departments and within industry. Each of these spheres of organizational and authority structures are inter-connected and in relating Lawton’s socio-political system to educational endeavours, it is clear that curriculum development should embrace the ideas of these three domains of thought. Universities pride themselves on the belief that ‘tertiary teaching is informed by research’ and that curriculum development is empowered by research. With respect to tertiary chemistry curricula development, it has been shown in Chapter 3 that Australia lacks a ‘chemical education culture’, particularly with respect to research into the learning and teaching of chemistry both at the secondary and tertiary levels. It is thus apparent that this is a constraint impeding progressive reform of chemistry curricula, particularly in the university sector. Further, it has long been argued by the chemical industry that tertiary chemistry courses could be made more ‘relevant’ if the content had industrial chemical significance and that the curricula showed how fundamental chemical principles underlie modern industrial chemical processes. In Chapter 5, it was shown how the present Australian Federal Government has attempted to streamline scientific research in all sectors to focus on a selected number of ‘research priorities’ to progress the ‘scientific culture of the nation’. These research priorities have a chemical basis which should be identified within tertiary chemistry curricula, particularly at the Year 1 level.

Lawton’s economic system is concerned with the distribution of resources. The resources of science ultimately involve scientific knowledge and processes. The generation of these is dependent either directly or indirectly on finance. It has been argued (see Chapter 5) that universities have been starved of Federal Government
funding for at least the past decade and within universities, ‘science’ has not had its ‘fair share’ of the ‘operating budget’. Similarly, the Australian professional science fraternity has argued that the Federal Government has not funded ‘science’ appropriately over the last decade and as a result, Australia is no longer at the forefront of scientific and technological development. As discussed in Chapter 5, it is this decreasing financial support for ‘science’ in Australia which indirectly relates to the lack of demand for tertiary science courses in Australian universities.

However, ‘scientific knowledge’ is also a ‘resource’ and the ‘economic element’ can be considered in terms of the economic benefits of chemical knowledge and that a tertiary chemistry qualification is the springboard to a plethora of career opportunities. It also relates to an emphasis that national development depends on sustainable science and technology industries and particularly on the chemical industry. The sustainability of the chemical industry depends on equating an increasing demand for trained chemists with a parallel increasing supply thereof and at this stage this equation is unbalanced with supply lagging demand, as has been revealed in Chapters 2 through 5. Furthermore, the Lawton economic system can also apply to chemical synthesis which is a fundamental characteristic of chemistry in terms of creating new matter via elegant, cost-effective synthetic routes. The inherent culture of chemistry is synonymous with elegant low-cost ways of synthesising products of significance which are beneficial to society and environmentally benign.

Lawton’s ‘communication element’ correlates with the ‘distribution of resources’ within the scientific community. Communication processes vary within different scientific communities and have increased in complexity over time. There are ‘formal’ and ‘informal’ aspects of the communication system. The former relate to ‘publication’ of scientific research in journals, official reports and conference proceedings whereas the latter relate to the discussions which scientists have among themselves. The creation of formal scientific professional societies has acted as a conduit for scientific communication both on a formal and informal basis. Also, there is an increasing evidence for scientists attempting to communicate science to the general public via the publication of ‘scientific novels’ and media appearances. However, as discussed in Chapters 3 and 5, such initiatives at least in Australia, have failed to change the negative perception of chemistry held by the general public.

Lawton has argued that the existence of a communication system as a characteristic of science underlies the essentially social nature of scientific processes
and this provides a crucial link between the chemical, educational and social components of the proposed new curriculum framework for the tertiary Chemistry course. However, ‘communication’ is achieved by use of a ‘language’ and in terms of the present research, Lawton’s ‘communication element’ relates directly to the ‘language’ of chemistry and the various ways that chemical knowledge is communicated and transmitted. The communication of chemical knowledge is more sophisticated than the dissemination of ‘rote-learned’ chemical knowledge since it involves visual conceptualization of chemical concepts and discourse between chemists must generate mental images that are congruent. Further, communication via publication is of paramount importance in terms of reward and recognition within the scientific community.

The rationality system which Lawton described was essentially the ‘science’ of a society. The rationality system of a scientific society is related to the processes of knowledge production. In society, science involves an attempt to describe and explain, in a coherent form, the observations which that community makes of phenomena in the natural world. Knowledge structures in science involve a network of theories which are based on specific ‘laws’ and ‘principles’. Lawton has argued that students’ appreciation of the significance of ‘knowledge’ is problematic unless an opportunity is provided for an understanding of the processes by which knowledge is produced.

The rationality system is also related to the way in which different societies base their explanations of the natural world on analogies, metaphors and models. Each ‘scientific society’ has its own set of acceptable procedures for directly investigating the natural world and these procedures change over time. The ways in which Australian society perceives ‘chemistry’ has been discussed in Chapters 3 and 5 and it appears that a major public educational campaign is necessary to change the negative image inherent in the mindset of the public.

The ‘rationality element’ also translates to the promotion of rational thought and action, which is another aspect of scientific literacy. In a chemical context, this element is implicit in ‘what chemists do’ and how they solve ‘real’ problems confronting society. It is this aspect which forms a major part of the public educational campaign required to change the negative public image of chemistry. However, these crucial elements need to be embedded in a Year 1 chemistry curriculum so as to encourage students to study chemistry as a major and provide
them with a clearly-defined career path as a professional chemist. Such education at
the foundation tertiary level will also allow students to critically contribute to the
public debate on the value of chemistry in society from an informed perspective.

Lawton’s ‘technology system’ refers to the existence and use of ‘tools’ to
carry out ‘tasks’ within society. To a major degree, there is a technology system
within science in the form of experimental work which is part of the ethos of science.
The institution of science involves activities other than those which are fully
internalized. Observation and explanation of ‘natural phenomena’ is the primary
function of science but this aim cannot be realized without the involvement and
cooperation of other sections of society nor are the results of scientific enterprise
retained fully within the scientific institution which generates them. ‘Technology’ is
the synergy between these two functionalities. Through the medium of technology,
the results and outcomes of scientific enterprise are communicated to a wider
audience than the scientific community for reasons of accountability and public
education. Thus, technology enables the production of scientific knowledge.
However, the technology system within society is not a sub-set of the scientific
enterprise. The relationship of technology to the natural world is different from that of
science. The latter is concerned with explanation without control whereas, technology
has the opposite focus. Nevertheless, these two areas intuitively interact in that
science provides ideas for technology to develop and technology provides
observations for science to explain. The technology enterprise is only one area of
interaction between science and society. Whereas, in general, technology directly
affects society, science also involves the socially responsible interactions with the
wider society whereby scientific knowledge is communicated and the power which
that knowledge provides enables an understanding and evaluation of the role of
society in promoting scientific progress. However, it has to be recognised that there is
a school of thought that believes that technology does not ‘generally’ benefit society
but only a small section of society.

Chemistry is inextricably linked to ‘technology’ and Lawton’s ‘technology
element’ relates to how chemistry enables not simply ‘technology’ but a wide range
of technologies. The transmission of knowledge thrust inherent in this element is not
only based on the direct interaction of chemistry with technology but the selection of
appropriate technology to achieve a beneficial outcome to society. It also relates to the
ways in which technology (mass spectrometry – as one example) has enabled
chemists to gain new insights into the molecular nature of matter. However, as discussed in Chapters 3 and 4, the chemists’ creative touch has become so well hidden in products and processes that chemistry has become the ‘invisible science’. It appears therefore that technology has not systematically recognised chemistry as a primary basis of its existence and sustainability.

The existence of an ethics dimension within the institution of science can be understood in terms of Lawton’s ‘morality system’ which he defined in terms of a ‘code of behaviour’ and distinctions between ‘right and wrong’. Within scientific communities, this is recognised as the ‘ethics’ of science whereby there are certain protocols, traditions and procedures which must be accepted and agreed to by practitioners. For example, there is an ethics protocol related to order of listing authors in the publication of research carried out by a team.

The ethics of the scientific enterprise has been shown in Chapters 3, 4 and 5 to be a key factor which influences the public image of scientists and chemists in particular. Chemistry is associated with weapons of mass destruction, the use of which is seen as a breach of the scientific moral code. In more general terms, chemistry is seen as being the ‘cause’ of many of the environmental problems of the world and being ‘detached’ from everyday life experiences. Thus, as far as chemistry is concerned, the transmission of the ‘morality element’ in chemical education has failed and this may be another reason why students are disenchanted with chemistry at both the secondary and tertiary levels.

Lawton’s ‘belief element’ is effectively the basis of the so-called ‘scientific method’ – suspension of belief until evidence is provided that qualifies the ‘rightness’ of the knowledge gained. Belief is a fundamental characteristic of science and in evidence in many ways. It relates to the way in which the scientific enterprise is conducted and the framework within which scientists conduct their investigations. Belief is manifested in the decisions which individual scientists make with regard to which experimental results they will accept and which they will discard. It relates also to whether a scientist will accept or reject another scientist’s theory or experimental work. Scientific progress is dependent upon such judgements. In chemical education, the belief system dictates that students are exposed to the concept of ‘organized scepticism’ or ‘nothing should be taken for granted’. This is an essential part of the learning process and enhances student interest in the curriculum. Indeed, it might be
argued that students should exercise disbelief unless evidence is presented to convince them.

Lawton explained his ‘aesthetic system’ in terms of ‘art and entertainment’ and the standards which define ‘quality’. Thus, a sense of ‘beauty’ underlies ‘aesthetics’. However, the nature of aesthetics is such that there are no clearly defined objective rules by which scientific ‘quality’ or ‘beauty’ is judged. The aesthetic dimension can best be measured in terms of the quality of a scientist’s work and passionate view of the natural world.

With respect to chemistry, the ‘aesthetics element’ relates to the ‘beauty of chemistry’ in both its physical and intellectual manifestations. Atkins, 2002 has qualified this by stating that ‘well-taught chemistry reveals the beauty and simplicity of the world and the scientific method exposes’ and ‘chemistry is made up of a few simple ideas and so much can be explained by so little’. Students therefore need to understand that elegant solutions to a chemical problem are likely to gain greater recognition than less elegant ones and that chemistry has an aesthetics dimension. However, the public image of chemistry is essentially the opposite – chemistry is aesthetically detrimental to society and hence the inclusion of this element in chemical education has also failed. It appears that chemistry has not been taught with the appropriate level of passion for its innate qualities and exceptional beauty and thus the aesthetics element of a chemistry curriculum is a vital contributor to increasing the interest of students in the course.

The last of Lawton’s elements is ‘maturation’ – knowledge must be mature for effective transmission. Among the scientific community, chemistry is acknowledged as the ‘central science’ as well as one of four ‘enabling’ sciences. It is an undisputed mature science, developed over several centuries. With respect to chemical education, the maturation element is best expressed in terms of the history and philosophy of chemistry which is a frequently neglected inclusion in tertiary chemistry courses. By inclusion of Lawton’s maturation element in chemistry curricula, it is possible to show how an understanding of chemistry enables an understanding of other sciences such as biology and that the boundaries of chemistry are virtual and flexible. It has been discussed in Chapters 3 and 4, that chemistry needs to ‘redefine itself’ and ‘remove its boundaries’ if it is to embrace the immediate challenges of the 21st century. Tertiary chemistry students need to be made aware of these challenges and be shown how the ‘maturity of chemistry’ enables their accomplishments.
The third premise on which the proposed Chemistry 1 curriculum framework is based is the Fensham ‘social responsibility of science’ philosophy which he has so eloquently summarized as ‘science has to be socially meaningful’ and ‘science education for all is essential to understand the complexity of the world and to be able to understand interpretations of these complexities from an informed viewpoint’ (Fensham, 1988). This philosophy has been discussed in Chapter 3 in terms of providing a new vision for chemical education in the 21st century and in terms of being of particular relevance to a new curriculum framework for the Chemistry 1 course. With respect to the latter, the social responsibility of chemistry is manifested in numerous ways, most importantly by revealing the benefits of chemistry to society, its quality of life and the standard of living. In simple terms, consumer chemistry, pharmaceutical chemistry, polymer chemistry, agricultural chemistry, forensic chemistry, green chemistry and environmental chemistry can be underpinned to reveal a profound social emphasis and impact and this aspect will be discussed in Chapter 7.

These inter-related and interactive three premises form the basis of the proposed Chemistry 1 curriculum framework and therefore form the foundation or ‘first level’ of the framework and the connectivity of these is shown in Figure 6.1. The overall curriculum pedagogy flows from this foundation framework which is developed in Chapter 7 as a crucial part of the ‘theoretical statement’.

Fig. 6.1  A primary curriculum framework for a Chemistry 1 course incorporating Atkins ‘Simple Ideas’ concept, Lawton’s ‘Elements of curriculum design’ and Fensham’s ‘Social responsibility of science’ philosophy
6.2.5 Responses to the proposed preliminary curriculum framework

Subsequent to the publication of ‘The Chemistry 1 course: a critical element for change’ (Hill, 2003) (Appendix 4), some twenty-five responses were received, most of which simply indicated that ‘the restructure of the tertiary Chemistry 1 course in Australian universities was long overdue and that any attempt to do so was to be applauded’. Five responses were more constructive and these are summarized in Table 6.1.

Table 6.1 Responses to the proposed Chemistry 1 curriculum framework.

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<th>RESPONDENT</th>
<th>SUMMARY RESPONSES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hewavitharana (2004)</td>
<td>• Most chemistry students complete only one chemistry (tertiary) course and hence the content of the Chemistry 1 curriculum is critical in terms of what they need for their future science career.</td>
</tr>
<tr>
<td><a href="mailto:Amitha_Hewavitharana@health.qld.gov.au">Amitha_Hewavitharana@health.qld.gov.au</a> (A trained chemist in the Queensland Health Scientific Services)</td>
<td>• It is particularly important to teach modern laboratory techniques – spectroscopic techniques rather than basic analytical techniques such as titrations.</td>
</tr>
<tr>
<td></td>
<td>• Teaching students how to communicate chemistry to other scientists is extremely important.</td>
</tr>
</tbody>
</table>
chmigorn@nus.edu.sg
An Associate Professor in the Department of Chemistry, National University of Singapore.

- Abolish completely all divisions of chemistry in Years 1 and 2.
- Teach all chemistry in parallel on the basis of ‘problems first, methods to follow’. Students do not need to know how to do titrations – they need to know how much of something is in a piece of material.
- Problem solving in Chemistry 1 should be sequential from ‘composition of matter: forces driving change to transformations of matter. Hence the concept of ‘acid-base titrations’ should be taught in terms of ‘amphoteric amino acids’ both in lectures and laboratories, simultaneously. Thermochemistry should be taught in terms of respiration and combustion.
- Computer animation should start on day 1 in the Chemistry 1 course to illustrate how molecules interact and which interactions are successful and why.
- The problem with chemical education so far has been fragmentation and incoherence. Integration and concentration on
| **Philp (2004)**  
| don@procass.com.au  
| (An industrial chemical consultant)  
|  
| solving problems rather than teaching methods, is the way forward.  
| • The need for chemists to take up the opportunity to shape the destiny of chemistry in Australia and then rise to that challenge is critical in my opinion for enhancing and increasing the return from our mineral resources.  
| • In making the Chemistry 1 course more exciting and more relevant both as an enabling science and as a solution to many of the problems of the civilized world, perhaps we need to tackle the curriculum top-down so that we than catch the attention of industry.  

| **Maerschel (2003)**  
| Richard@berryessa.com.au  
| (Director of a Chemical Consultants company)  
|  
| • Chemistry has had a bad press for a long time.  
| • There is a deeply pervasive belief that the ‘natural’ remedies (in medicine) are better than anything science can produce simply because they are ‘natural’. This is surely, a monumental disdain for chemistry.  
| • Exciting and relevant chemistry needs to be introduced to 15-16 year olds by showing them the
benefits of ‘chemistry in context’ – ‘what difference an atom makes – an O here and N there’: ‘meat for one, poison for another’ (history of tomatoes, lead, arsenic, plant alkaloids).

- Address the badly understood chemical terms such as ‘chemical’, ‘organic’, ‘natural’ and ‘genetically modified’.

<table>
<thead>
<tr>
<th>Wilson (2003) <a href="mailto:lynandivan@comcen.com.au">lynandivan@comcen.com.au</a></th>
</tr>
</thead>
<tbody>
<tr>
<td>(A retired Associate Professor in the Department of Chemistry, Monash University)</td>
</tr>
</tbody>
</table>

- I believe that the key decisions about careers are made far earlier than we normally assume. The process is well under way by the end of primary schooling.

- If chemists can play a part in early presentation of the numerate sciences, they may serve the community widely.

- If the goal of our Year 1 studies is to gain chemistry degree students or to build up our research team, that does not respect the learners and should fail.

- Our central goal in Chemistry 1 should be to meet what the learners see as their interest. Teachers are often poor judges of what that might be.
These thought-provoking responses to the author’s publication ‘The Chemistry 1 course: a critical element for change’ (Appendix 4), echo the imperatives for reform of the Chemistry 1 course as summarized in Chapters 2 to 5 inclusive and, in addition, provide some useful insights into the general structure of such a reform process. Some of the responses are noteworthy in the structure of the author’s theoretical statement developed in Chapter 7. The most important of these is that the ‘content’ of the Chemistry 1 course is critical to give all students foundation knowledge of chemistry. Further, the content should eliminate the traditional divisions of chemistry, it should be based on using chemical knowledge to solve problems and it should contain practical exercises which emphasise modern (instrumental) laboratory techniques. The responses also address the learning and teaching of chemistry at the Year 1 level. The use of chemical animation is believed to be essential as a learning aid and exciting and relevant chemistry must be included. Further, the central goal of Chemistry 1 should be to deliver what the learners want rather than what the teacher decides to give.

Hence, it appears that the Australian chemical fraternity does indeed recognize the acute need for such reform, but in general terms it is reluctant to embrace such reform in view of the magnitude of the associated constraints and ambiguities. To embrace the required reform is the primary challenge of the present project and the proposed new curriculum framework for the Chemistry 1 course is discussed in detail in Chapter 7.

6.3 CONCLUSION

This chapter has reviewed and summarized the major imperatives driving change to the curriculum framework of the Chemistry 1 course. A preliminary curriculum framework is proposed based on three inter-related and interactive philosophies – the Atkins ‘simplicity of chemistry’ principle, Lawton’s curriculum theory and Fensham’s ‘social responsibility of science’ thesis. This first stage in the construction of a new Chemistry 1 curriculum framework has been published in order to test the strength of the reform agenda within the Australian chemistry fraternity by soliciting feed-back comments which are incorporated into the presentation and discussion of the full and detailed curriculum framework in Chapter 7, thereby forming the ‘theoretical statement’ of this thesis.
BIBLIOGRAPHY

American Association for the Advancement of Science (AAAS) (1989), ‘Science for all Americans: A project 2061 report on literacy goals in science mathematics and technology’, Washington DC.


CHAPTER 7
A NEW CURRICULUM FRAMEWORK
FOR THE CHEMISTRY 1 COURSE

7.1 INTRODUCTION

The purpose of this chapter is to make a theoretical statement defining in broad outline a theoretical curriculum framework for the tertiary Chemistry 1 course. Throughout Chapters 2 to 5, numerous imperatives for change have been identified, researched and discussed which are summarized here in terms of providing a set of principles for a new approach to teaching chemistry at the Year 1 level in Australian universities.

In Chapter 2, the concerns of Heads of Chemistry Departments, as highlighted in the structured interviews program, were analysed and discussed particularly with respect to their concerns on the Chemistry 1 course. The main driver for re-invigorating the Chemistry 1 course is the declining student intake into chemistry at the Year 1 level as compared with a constant or increasing student intake into the Chemistry 1 course. This trend which has been apparent for at least the last decade signals that mainstream chemistry is in decline and that the Chemistry 1 course is primarily serving the needs of other sciences, particularly the biological sciences, as a Year 1 ‘service unit’. Thus, the bulk of students taking Chemistry 1 do not continue with chemistry in the subsequent years of their degree course and their attitude towards studying chemistry is at best impartial. A related problem is that the students enrolled in Chemistry 1 derive from a diverse range of educational backgrounds particularly with respect to education in chemistry. Although it is expected that commencing Chemistry 1 students have studied one or more sciences previously, it is recognized that a significant proportion will not have studied chemistry to Year 12. Mature-age entry students may be in either of these categories but the time-lag since leaving school is often an additional handicap. A further concern highlighted by the Heads of Chemistry is that the mathematics skills of Chemistry 1 students is generally below the standard required for the problem-solving skills inherent in the current course. Their main concern is that as a result, the Chemistry 1 course has
progressively been ‘softened’ and thus its standard and prestige as the leading Year 1
science course in Australian universities has, they believe, declined.

Other concerns related to the organization and content of the Chemistry 1
course. The time-honoured division of the course into four main parts – analytical,
inorganic, organic and physical, still dominates the overall structure and hence
students have difficulty relating fundamental chemical concepts across these artificial
boundaries. For example, a typical perception of students is that ‘bonding’ in
inorganic compounds is ‘different’ from that in organic compounds. Such
misconceptions add to the learning difficulties of the students. Most Heads of
Department concur that there is ‘too much content’ in the present Chemistry 1 course
such that it is difficult to construct basic chemical concepts with contextual emphasis
– particularly a social emphasis. It was appreciated that the physical chemistry section
of the course is seen as too difficult but this is believed to relate to the lack of basic
mathematics skills of the students. Further, the organic chemistry section is still too
traditional in terms of content and there is much pressure from Biochemistry
Departments to relate basic organic chemistry directly to biochemistry and hence to
the study of living systems.

It was further apparent from these interviews that as a result of a content-
saturated course, there was little scope for innovation in terms of including ‘leading-
edge’ chemistry in the course, thereby addressing the excitement factor. Further, with
the present course structure, it is inevitable that ‘history and philosophy of chemistry’
does not get a mention and neither does the ‘social responsibility of chemistry’.

The interviews also revealed that there was a reluctance to allow new teaching
methodologies, particularly those involving IT to dominate the teaching of Chemistry
1. It was appreciated that these new methodologies can significantly enhance the
learning process for students, particularly use of interactive multimedia, but student
quality assessments of the Chemistry 1 course consistently show that ‘face-to-face’
teaching is the preferred methodology.

The interviews also revealed that Heads of Chemistry Departments were
aware of the major changes in the school certificate chemistry over the last decade
with less core chemical content progressively included. They tended to correlate this
with the declining student intake into chemistry since they believe that the more open
and flexible Year 12 chemistry course ‘turns students off chemistry’ and hence those
who continue into tertiary study are attracted to science courses which offer
immediate greater appeal than does chemistry. The present (Victorian State) VCE Chemistry course was examined in Chapter 3 and although many of the shortcomings which are apparent in the Chemistry 1 course have been overcome, the VCE course, for example, is particularly light-on in terms of emphasizing the social responsibility of chemistry. This is perhaps its critical failing and possibly a reason why students are turned away from chemistry at the secondary-tertiary interface. It was shown in Chapter 3 that there are other factors in ‘secondary school science’ which impact on the declining image of chemistry at the secondary-tertiary interface. In many secondary schools, particularly in the private sector, several science subjects are offered pre-VCE/HSC. In particular in this context, the biological sciences are prominent and it appears that career opportunities are highlighted at this early stage. Chemistry at the secondary level has no clearly identified career path and it is not even seen as an essential pre-requisite for a science career. In Chapter 3, this issue was emphasized as a critical contributing factor to the continuing demise of chemistry in Australia and it necessitates urgent attention, particularly in terms of addressing the acute shortage of secondary school science teachers and providing professional development opportunities for this group and chemistry career opportunity sessions for school career advisors. There also needs to be more interaction between university Chemistry Departments and secondary school science teachers to enforce the centrality of chemistry studies as an essential underlay to a science career. Such interaction could also involve Years 11 and 12 students doing ‘hands-on’ exercises in chemistry department teaching laboratories. A further problem is that in general, mathematical skills at pre-VCE/HSC level are patchy and at Years 11 and 12, these skills are not intensively developed since much of the chemistry course only requires limited mathematics ability.

The ‘health’ of Australian university Chemistry Departments was also discussed in Chapter 3 since it is believed that this has a major impact on the effectiveness of the Chemistry 1 course and on the ability of these departments to attract students. It was concluded that a ‘healthy’ chemistry department is one which has a quality teaching program, a quality research profile and a strong employment profile for its graduates. In terms of attracting students into Chemistry 1, it is clear that pre-enrolment advice has to be directed to emphasize that other sciences such as forensic science, environmental science and medical science all have a fundamental chemistry base and that since ‘science’ involves ‘measurement’, competency in
mathematics is an essential requirement. Further, it needs to be emphasized at this early stage that ‘chemistry’ offers a wide range of interesting and challenging careers.

The general review of chemical education developments in Australia, (presented in Chapter 3) showed that there has been no comprehensive restructuring of Chemistry 1 over at least the last decade. Such changes that have occurred have been largely cosmetic except for the (relatively) new context-based course at the University of Adelaide. Further, new teaching methodologies have been introduced gradually and with a measure of reluctance. It was argued in Chapter 3 that this ‘reluctance to change’ may well be an outcome of a general lethargic reaction by Chemistry Departments towards chemical education developments globally and a lack of respect for chemical education research in Australian universities. It was shown that relatively little chemical education research is being conducted in Australia, particularly in terms of learning and teaching issues relating to the Chemistry 1 course.

The vast international chemical education literature from 1990 to date was reviewed in Chapter 4 and although there was little of direct relevance to the Chemistry 1 course, there was much of indirect relevance. In particular, the Atkins ‘diet of chemistry’ proposal (Atkins, 2002) and his basic premise that ‘chemistry is essentially a collection of a few simple ideas’ is of pivotal significance in the context of designing a new curriculum as the major focus of the present project. Other significant ideas emerged from this review related to the teaching of chemistry as an ‘enabling central science’, the emphasis on retaining a significant proportion of laboratory chemistry in the Chemistry course and the widespread use of new teaching methodologies in teaching chemistry generally. It is also apparent that ‘First Year University Chemistry’ is supported by a wide range of textbooks which are now complete teaching/learning packages.

The interviews with Heads of Chemistry Departments revealed numerous constraints on implementing changes in Chemistry 1. Foremost of these was declining Departmental operating budgets which are directly proportional to increasing student/staff ratios and decreasing proportions of face-to-face teaching together with an inability to address declining quality of departmental infrastructure. Heads were critical of increasing applied pressures to enhance quality of teaching, to maintain high pass rates, to keep up with the ‘IT revolution’ and to maintain legislative levels of OH&S in the Department. Heads believed that it was very difficult to reverse the
trend of ‘chemistry’ becoming a ‘service course’ at the Year 1 level since Chemistry Departments have insufficient resources to offer ‘niche’ (chemistry) degree courses such as medicinal chemistry, forensic chemistry and environmental chemistry, either as independent courses or as ‘double-degree’ courses. Hence, Chemistry is unable to effectively compete for and attract the highest calibre students into the Chemistry 1 course. Heads of Chemistry believe that in such a competitive internal climate, many smaller chemistry departments will not survive and are likely to be subsumed by other, more financially viable science departments. Heads of Chemistry believe that this will further exacerbate the demise of chemistry in Australian universities. In such a pessimistic climate, it is a challenge to create a Chemistry 1 course that will enhance the image of chemistry in Australia.

The scope of this chapter involves developing a curriculum framework for a Chemistry 1 course which is based on a set of principles, defined below, which are assimilated into a theoretical statement of the structure of such a framework. These principles derive directly from the data fields of this research, as discussed in previous chapters as summarized in Table 7.1 below.

**Table 7.1 The principles underlying the design of a Chemistry 1 curriculum framework.**

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Lawton’s ‘systems’</th>
<th>Atkins ‘simple structure of chemistry’</th>
<th>Fensham’s ‘social responsibility of chemistry’</th>
<th>Australian chemical education developments</th>
<th>International chemical education developments</th>
<th>Concerns of Heads of Chemistry on the structure of the Chemistry 1 course</th>
<th>Constraints impeding change to the Chemistry 1 course</th>
</tr>
</thead>
<tbody>
<tr>
<td>All introduced in Chapter 6</td>
<td>Discussed in Chapter 3</td>
<td>Discussed in Chapter 4</td>
<td>Discussed in Chapter 2</td>
<td>Discussed in Chapter 5</td>
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The principles on which the proposed curriculum framework is based are:

- Reform of tertiary chemistry education is necessary in terms of curriculum, pedagogy and learning outcomes.
- Such reform is impeded by a plethora of constraints, particularly the ongoing financial constraints placed upon the tertiary chemistry teaching and learning environment.
- The proposed new Chemistry 1 course curriculum framework must embrace contemporary educational theories and relate modern chemistry to its historical development, reveal its enabling features in technological development and emphasise its inherent responsibilities to society and environmental sustainability.
- The proposed Chemistry 1 curriculum framework should adopt Lawton’s generic elements of curriculum design to provide a theoretical base.
- The proposed Chemistry 1 curriculum framework should be developed using Atkins ‘Simple ideas of chemistry’ concept as a central guide to the selection of content.
- The proposed Chemistry 1 curriculum framework should embrace Fensham’s ‘social responsibility of science’ philosophy as a platform for emphasising the relevance of chemistry in the contemporary world, its commitment to a sustainable society structure and the need to use chemistry in an ethical manner.
- The teaching methodology of the proposed new Chemistry 1 course must recognize the limited chemistry background of many students and also their limited mathematical skills.
- The proposed new Chemistry 1 course should retain a significant experimental component which should reveal the ‘excitement’ of chemistry and be based on the principles of ‘green chemistry’.
- The proposed new Chemistry 1 course should be enriched and empowered by contemporary IT learning and teaching methodologies.
The proposed Chemistry 1 curriculum framework should have identifiable learning outcomes in terms of chemical literacy, an ability to think scientifically and to solve scientific problems and an appreciation of the enabling ability of chemistry which assists the progression of technology in an environmentally sensitive manner.

The scope does not provide for a detailed description of the curriculum for Chemistry 1 however, a detailed description of one core topic – chemical thermodynamics – is discussed in Chapter 8 as an exemplar of the effectiveness of the proposed framework and its practical application.

The envisaged outcome of this chapter is the emergence of a new curriculum framework for the Chemistry 1 course which is based on contemporary educational theory and identifies and remedies the shortcomings of the existing Chemistry 1 course in Australian universities and promotes a new paradigm of learning in basic chemistry which reveals how key chemical concepts can be used repeatedly to understand complex and diverse chemical phenomena. It also reveals the richness and rigor of chemistry, the excitement and, in particular, the enabling power of chemistry to solve problems of social, economic and environmental significance.

### 7.2 THE FUNDAMENTALS OF THE PROPOSED CURRICULUM FRAMEWORK

#### 7.2.1 Pathways to and rationale for a new Chemistry 1 curriculum

The various data fields of this research have identified the need for a new curriculum for the Chemistry 1 course and the main pathways leading to reconstruction and a rationale supporting reform are summarized below:

- Interviews with Heads of Chemistry Departments revealed concern over the present structure of the Chemistry 1 course in Australian universities but identified numerous constraints, principally financial, which impede a systematic curriculum review.

- There is a serious lack of chemical education research in Australian universities and a general unawareness of chemical education developments globally.
Although school chemistry curricula have been restructured to focus on student-centred-learning, the social dimension of science has not been sufficiently emphasized to attract students to tertiary science studies.

The modifications to Chemistry 1 which have taken place have concentrated on more attractive ways of learning chemistry, such as context-based and problem-based learning but have not applied contemporary educational theory to inform such pedagogies.

There has been a greater emphasis internationally to address the declining demand for tertiary chemistry courses. Part of this effort has been directed to the restructuring of senior secondary school science and in this context, the Salters’ (context-based curriculum) appears to have been particularly successful in increasing awareness of chemistry as the central enabling science from a social, economic and environmental perspective.

Unlike Australia, there is a rich chemical education culture and research base in the USA, UK and Europe, which is informing and driving progressive change in chemical learning and teaching methodologies at both the secondary and tertiary levels with a chemical literacy goal.

Modifications which have taken place with respect to the tertiary chemistry curricula at the Year 1 level internationally have concentrated on a holistic, integrated approach to the teaching of chemistry in context with emphasis on the exciting developments of chemistry which directly benefit society and sustain rather than deteriorate the environment.

From these many and diverse drivers of change in contemporary chemical education, it is apparent that there has been no detailed review of the Chemistry 1 course either in Australia or internationally with a view to addressing the concerns on the structure and effectiveness of the existing course.

The proposed Chemistry 1 curriculum framework is based on the assimilation of three educational philosophies: the ‘simplicity of chemistry’ (Atkins), the ‘educational systems’ (Lawton) and the ‘social responsibility of science’ (Fensham). This is the essential new contribution to the Chemistry 1 debate proposed by the Author and is subsequently referred to as the ‘Hill curriculum framework’. Unlike present Chemistry 1 curricula which are essentially ‘chemistry content’ based, the proposed curriculum framework gives approximately equal weightings to the selected
educational philosophies, thereby recognizing that ‘content’ has to be associated with educational theory and social responsibility dimensions.

7.2.2 Atkins ‘simple ideas of chemistry’ proposal

The so-called Atkins ‘diet of chemistry’ has been widely publicized globally within the chemical education community. Atkins is a widely sought-after plenary speaker at major international chemical education conferences and his plenary lecture at the 17th International Conference on Chemical Education (17 ICCE), Beijing, 2000 (Atkins, 2002) provided the impetus to include his ideas in the present curriculum framework design project.

Atkins proposes that ‘chemistry’ is made up of nine key concepts: matter consists of atoms, atomic structure accounts for periodicity, bonds form by electron-pair sharing, shape is of paramount importance, there are residual forces between molecules, energy is conserved, energy and matter tend to disperse, there are barriers to reaction and there are only four types of reaction. These key concepts are embedded in his well-known and widely adopted text ‘Chemistry: Molecules, Matter and Change’ (Atkins & Jones, 1997) and Atkins has published a separate text on the second key concept, which is more of a novel than a text-book (Atkins, 1995).

Atkins basic philosophy is a compelling one: ‘well-taught chemistry reveals the simplicity of the world and it is the scientific method that exposes this’ and ‘chemistry is made up of only a few simple ideas’ and ‘the world is full of the wonders of chemistry’. This is the critical message that has to be transmitted to science students both at the secondary and tertiary levels. It is immediately obvious that the nine key concepts relate to chemistry as a unified science and not to the artificial division of chemistry into four parts which gives the philosophy great appeal. Also, Atkins gives an insight into what ‘well-taught chemistry’ means – and ability to ‘think macroscopically’ but ‘understand microscopically’. Atkins key concepts provides a platform of learning for chemistry which collectively reveal how chemistry can explain complex scientific phenomena in the physical world via a series of organized learning steps which are inter-connected. In the words of Atkins: ‘From so little, we can account for so much’. Atkins has provided a wealth of ideas on teaching chemistry effectively. Firstly, why study chemistry? Atkins believes that it is necessary to emphasize what differentiates chemistry from other scientific disciplines. Chemistry involves the synthesis of ‘new forms of matter’ – pharmaceuticals, polymers, detergents, explosives to name a few. Chemistry embodies the ingenuity
and imaginative breadth of a modern molecular science. Other science disciplines such as biology are largely pitched at the macro level – chemistry is pitched at the micro (molecular) level which makes it a quantitative science, full of rigor and depth. Secondly, Atkins answers the question ‘What is chemistry?’ It is changing the ‘natural’ into the useful ‘un-natural’ via chemical synthesis. This leads to the value added significance of chemistry and to economic profit. Chemistry is fundamentally the ‘transformation of matter’ and processes such as dyeing and colouring, tanning, metal extraction and making of alloys have been known for centuries. The Atkins philosophy also addresses the ‘how’ and ‘why’ aspects of chemistry. The laws of thermodynamics fundamentally address these questions in terms of the behaviour of matter at the molecular level and it is chemical thermodynamics which explains natural biochemical processes and chemical kinetics which explains the rate and the mechanism by which biochemical processes occur. Biological processes in general can only be understood by chemical modelling techniques which are premised at the micro-molecular level. Atkins (2002) proposes that ‘By understanding how simple molecules interact, we are able to at least partially understand how more complex molecular systems behave’. This in very simple and elegant terms is promoting the effectiveness of ‘computational chemistry’ as an emerging indispensable adjunct to biochemistry.

Atkins believes that there are many leading-edge chemistry topics which can be described in similar simple terms. For example, the social relevance of chemistry has seen the emergence of ‘green chemistry’ – revealing a ‘chemists care’ ethic. Similarly, chemistry is responsible for replacing the toxic agricultural pesticides and herbicides with ‘insect growth regulators’ – revealing an ‘environmental management’ ethic and chemistry is producing new ‘clean’ energy forms – revealing its commitment to the ‘Kyoto Accord’ on ‘greenhouse gases’.

Thus, the Atkins philosophy on the ‘constitution of chemistry’ and the teaching and communication of chemistry provides a constructive platform for development into a curriculum framework for a Chemistry 1 course.

7.2.3 Lawton’s educational systems

The second fundamental of the proposed curriculum framework is the Lawton so-called ‘systems’ of educational theory (Lawton, 1973, 1975, 1983, 1986, 1988, 1989). Before these ideas can be incorporated into the proposed curriculum design project, it is necessary to recognize that an educational program requires a framework
on which it is built if it is to be widely understood and if it is to have validity beyond the isolated contributions which, with respect to the Chemistry 1 course, have been identified and discussed in Chapters 2, 3 and 4. Lawton (1989) has made significant contributions to the complex area of curriculum design and has extended the early pioneering work of Tyler (1949), Stenhouse (1975/1977) and others in constructing a curriculum framework based on the concept of education as a process of transmission of culture. Lawton (1989) has suggested nine cultural ‘systems’ which are important characteristics of a society and which are therefore worthy of transmission to future generations. These are: the socio-political system, the economic system, the communication system, the rationality system, the technology system, the morality system, the belief system, the aesthetic system and the maturation system. Although these systems are abstract in construct, they are adopted in this project and modified to apply specifically to the chemistry component of science education. This presents a major challenge since the ‘systems’ are so general in description and apply to any curriculum. He illustrates them by application to generalist educational principles and they are interpreted here for the purpose of creating the theoretical basis of the proposed Chemistry 1 curriculum reform. Therefore, parallels to Lawton’s systems are proposed in 7.3 and form the platform for the proposed new curriculum framework for the Chemistry 1 course.

In designing a new curriculum framework for this course, note is taken of McColl’s thesis (2002) that a -

(m)ore explicit picture of science should be presented – one based on

a greater awareness of how scientific knowledge evolves. It must be recognized that ‘science’ is a product of the thoughts and ideas of individuals based on interpretations and interactions with their environment, including their social and cultural environment. Hence, there is much scope for examining and analysing the way that scientific knowledge is produced. If all that is communicated to students about science are its ‘laws’ and ‘theories’ which are often portrayed as dictating the way nature behaves rather than explaining it, students only encounter the conclusions of science and not its processes. (p.93)

Further, Schwab (1964) referred to -
The unmitigated rhetoric of conclusions in which the current and temporal constructions of scientific knowledge are conveyed as empirical, literal and irrevocable truths. (p.24)

McColl concludes that -

(i)n addition to other difficulties that this process presents, it inevitably leads to a misunderstanding of the limitations of the applicability and fallibility of scientific ‘laws’ and ‘theories’. (p.93)

A rich educational theory literature relates to ‘curriculum development’. In this project, the curriculum framework developed by Lawton (1973) is adopted which consists of four elements – ‘aims and objectives’, ‘content’, ‘organization’ and ‘evaluation’ – all interconnected and interactive, as shown in Figure 7.1.

![Diagram of Lawton's generic curriculum framework]

This particular curriculum framework was selected because McColl (2002) has elegantly reviewed the complex literature of curriculum development and has successfully applied the Lawton curriculum framework to develop a new curriculum for secondary school physics based on the history and philosophy of physics which has many parallels to the present project.

7.2.4 Fensham’s social responsibility of science philosophy

The third fundamental of the proposed curriculum framework for the Chemistry 1 course is Fensham’s ‘social responsibility of science’ philosophy. This has been discussed in detail in Chapter 3 and it is shown that there is much scope for including this philosophy into science curricula generally but in particular in school
and university science courses. It is evident that Fensham’s basic philosophy that ‘science needs to be socially responsible’ and that ‘all society should be scientifically literate to cope in the modern world’ is conspicuously overlooked in most school and university science curricula in Australian educational institutions.

Pre-empting the inclusion of the Fensham philosophy in the design of a new curriculum framework for the Chemistry 1 course, the author has published a paper titled ‘Fensham’s ‘Science for All’ vision: A Chemistry perspective’ (Hill, 2005) (Appendix 4) which emphasizes the crucial importance of this philosophy in science curricula generally and in chemistry curricula in particular.

Hence, the basis of the present curriculum framework design has been established in terms of using the Lawton basic curriculum framework shown in Figure.7.1 and overlaying this with Lawton’s ‘systems’ and Atkins key chemical concepts and incorporating Fensham’s ‘social responsibility of science’ philosophy, as shown diagrammatically in Figure.7.2.

This complex structure embraces the most widely acknowledged key principles of educational theory, the most simplified structure of chemistry, the most respected ‘cultural elements’ of knowledge transmission and the most highly regarded belief that all society should be scientifically literate. It therefore incorporates the latest ideas and innovations for the transmission of chemical knowledge to students of diverse educational backgrounds and learning abilities and should provide a realistic solution to the focal problem of this project – namely the demise of chemistry as a course of study at the tertiary level.
7.3 DEVELOPMENT OF A CURRICULUM FRAMEWORK FOR CHEMISTRY 1 – ASSIMILATING THE ATKINS, LAWTON AND FENSHAM PHILOSOPHIES AND INCORPORATING THE HILL PRINCIPLES OF CURRICULUM DESIGN

The first of the elements incorporated in the Lawton curriculum framework is ‘aims and objectives’ and this is basically the rationale for this present research project. The overall aim of the proposed new curriculum framework for the Chemistry 1 course is to develop an innovative course which engages students in the study of the science of chemistry and which intrinsically reveals the enabling power of chemistry to solve many of the social, economic and environmental problems which constantly challenge the sustainability of human existence. An equally important aim is to embrace the many changes in pedagogy related to the teaching of chemistry at the tertiary level, especially the philosophy that effective education is achieved through understanding and application. In this context, the attributes of ‘problem-based learning’ are acknowledged in conjunction with ‘context-based teaching’. A further aim is to include ‘captivating factors’ into the curriculum framework, which not only entice students to engage with chemistry but also reflect the most spectacular leading-edge chemistry developments so that students can appreciate the significance of chemistry in exerting a primary influence on the ‘technological age’ and the benefits of chemistry to society and its cultural and economic development. An additional aim in this context is to introduce where appropriate, aspects of the history and philosophy of chemistry balanced with examples of contemporary chemistry. A primary aim is to reveal how the boundaries of chemistry have widened very considerably over recent decades such that chemistry relates directly and empowers other traditional sciences, particularly the biological sciences thereby revealing chemistry as the ‘central science’. In this context, it is important to emphasize that chemistry is closely linked to the emerging ‘new sciences’ such as nano-science and sustainable science. A major aim of the proposed curriculum is the adoption of new teaching methodologies and paradigms of teaching, particularly those involving the application of ‘information/communication technologies’. These are encouraged to enhance the learning experience of students by engaging them individually in the learning process. An overall aim is to develop a new Chemistry 1 course which fundamentally the participating students ‘enjoy’.
The conceptual separation of ‘aims’ and ‘objectives’ of the new curriculum framework is essential in that the ‘objectives’ are ‘short-term’ whereas the ‘aims’ have ‘longer-term’ significance. The primary objective is to ensure that the participating students achieve a level of competence in chemical literacy which empowers them to understand common scientific phenomena in the real world. The secondary objective is to provide the students with sufficient chemical knowledge and experimental skills which equip them to pursue further study in science as a basis for a challenging and rewarding professional scientific career.

It is proposed that the new curriculum framework for Chemistry 1 is made up of three inter-connected sections.

7.3.1 Assimilation of Atkins philosophy

The ‘content’ and ‘organization’ of the basic or core section of the proposed curriculum framework has essentially been provided by the insight of Atkins (2002) and his ‘9 key chemical concepts’ proposal. The ‘9 key chemical concepts’ suggest that the ‘essential chemistry’ for a Year 1 university chemistry course is comprised of three parts – the structure of matter, the transformations of matter and the interactions of matter, which address the ‘what’, ‘how’ and ‘why’ of chemistry. The proposed content of this section of the curriculum is shown in Fig.7.3 and encompasses the full range of topics included in a ‘traditional’ Chemistry 1 course.

![Diagram of Chemistry - The Central Science]

**Fig. 7.3** The content of Section 1: ‘Chemistry - The Central Science’

It is necessary to reorganize the content of each of these topics in accordance with the overall philosophy of the present curriculum design and this aspect is discussed in Chapter 8 with respect to ‘chemical thermodynamics’.
The second major section of the proposed curriculum framework recognizes the importance of chemistry in understanding biochemical systems. This section incorporates basic organic chemistry as the foundation for modelling complex biological processes leading to the basis of genetic modification technology. The rationale for the content of this section is given in a discourse by Price and Hill (2004) as a means of addressing the student drift towards the biological sciences. We have suggested that:

(a) an example of what can be done, and again taking the biological sciences as a 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 recognize that such interfaces between these disciplines are flexible and porous. 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 and an equally important issue to stress is that there are no realistic boundaries between the sciences. (p.18)

The proposed content of this section of the curriculum is shown in Figure 7.4 and is designed to not only glamorize traditional systematic chemistry but to reveal how such chemistry is vital to even a superficial understanding of living processes.
The third major section of the proposed curriculum framework recognizes that chemistry is fundamentally a human activity and therefore has a social responsibility. Topics included in this section reveal such social responsibility and are designed to emphasize the impact of chemistry on ‘caring’ for society and for the environment. The proposed content of this section is shown in Figure 7.5 and some of the topics are best constructed as mini-projects. Additional student-selected topics could be included to emphasize the ‘student-centred’ focus of the course and that knowledge is jointly constructed by both teachers and students. This feature also increases student’s enjoyment of the course and allows them to apply the chemical knowledge which they have learnt in section 1. It also embraces the new paradigms of learning, in particular, project work develops student competencies as ‘thinkers’, ‘discoverers’ and ‘constructors’ and induces student cooperation and emphasizes teamwork.

![Figure 7.5](image)

**Fig. 7.5 The content of Section 3: ‘Chemistry - The Sociological Connection’**

It should be emphasized that whereas the selection of topics in section 1 is not debatable, there is some scope for variation of topics in sections 2 and 3 to reflect particular research strengths of individual university chemistry departments and their need to emphasize specific aspects of chemistry to attract students. Based on an exhaustive review of the present structure of the Chemistry 1 course in Australian universities and its many short-comings, it is evident that the essential knowledge base for understanding chemistry is constituted by the topics in section 1 and these form a foundation of knowledge for understanding the frontier chemistry topics in Section 2. The accumulated knowledge of Sections 1 and 2 is sufficient to apply such knowledge to an appreciation of the social responsibility of chemistry and an ability to change the public image of chemistry by informed scientific opinion. These are the desired learning outcomes of the proposed curriculum framework.

Although it is important to give meaningful and attractive titles to each of the sections of the curriculum, it is not the intention of the author to propose such titles without widespread discussion with the chemistry academic community. However,
the following titles are provisionally suggested: Section 1, ‘Chemistry – The Central Science’: Section 2, ‘Chemistry – The Biology Connection: Section 3, ‘Chemistry – The Sociological Connection’. A more appealing title for the Chemistry 1 course overall could be ‘Chemistry – The multi-disciplinary science’.

The fourth major element of the Lawton approach to curriculum design is ‘evaluation’ of the constructed framework in terms of its effectiveness as an instrument of learning and teaching. The proposed curriculum framework for the Chemistry 1 course is based on the key concept of ‘student-centred’ learning and student engagement in the learning process. It is believed that only by imposing this strategy as a key driver of the curriculum can its overall effectiveness be guaranteed in terms of student participation in and enjoyment of the learning process.

7.3.2 Assimilation of Lawton’s educational systems

The second stage of development of a new curriculum framework for the Chemistry 1 course involves ‘overlaying’ Lawton’s ‘cultural systems’ template on the primary curriculum structure as described by a combination of Figures 7.3, 7.4 and 7.5. Such an ‘interfacing construct’ poses a significant challenge since the ‘cultural systems’ are described by Lawton in very general terms. The challenge is to translate the intent of each construct into chemical philosophy such that the educational impact of such systems is invoked from a chemical perspective.

In general terms the scope and flexibility of the proposed curriculum framework for Chemistry 1 offers a wide range of opportunities to incorporate and embrace Lawton’s cultural systems. Each of the topics included has scope for wider interpretation in terms of these systems thereby adding to the educational significance of the curriculum.

It is appropriate to firstly interpret the ‘systems’ in terms of a chemistry perspective and then show how these systems relate to the individual topics in the proposed curriculum. It is not the intention to provide an exhaustive correlation between the Lawton cultural systems template and the proposed curriculum framework but to reveal how these two constructs can be effectively combined.

It is recognized that the ‘nine systems’ proposed by Lawton are not necessarily ‘all embracing’ and there is scope for possibly proposing additional systems in some cases. It is also recognized that the order of the systems given in Lawton’s original discourse (Lawton, 1989) is not hierarchal and thus each system is assumed to be of equal significance in terms of curriculum design.
Perhaps the most appropriate approach to the interpretation of the Lawton systems is to reflect on their original definition - ‘those essential characteristics of science which should be transmitted to the next generation’ (Lawton, 1989) and then identify the essential characteristics of chemistry in terms of the systems. It then becomes obvious that these essential characteristics of chemistry must be embedded in the Chemistry 1 course curriculum if this is to reflect the fundamental enabling principles of contemporary educational theory.

Lawton first described his systems in a general sense as ‘universals’ of society which can be interpreted as the essential building-blocks of education in terms of transmission of knowledge. The Lawton systems, when applied to science education, therefore define the essential components necessary to achieve a scientifically-literate society and can be considered as the educational dimensions of science.

Lawton’s socio-political system is concerned with power structures and authority. Organizational and authority structures exist within science in three main spheres: teaching and research in universities, as government departments and in industry. These spheres are inter-connected and represent the scientific culture of a society. Lawton further characterized the power structures as authority in terms of the status, role, duty and obligation which are associated with such structures.

The realization of the social dimension of science is not a new phenomenon. In 1938, Hogben published his classic ‘Science for the Citizen’, the foreword of which encapsulates the thrust of Lawton’s socio-political system:

‘Science for the Citizen’ is partly written for the large and growing number of intelligent adults who realize that the impact of science on society is now the focus of genuinely constructive social effort. It is also written for the growing number of adolescents who realize that they will be the first victims of the new destructive powers of science misapplied. (p.11)

There are two important links here to the Lawton socio-political system and to the learning and teaching of chemistry. The first is that scientific literacy is the result of constructive social effort and the second is that science students having acquired scientific literacy are required to use their scientific knowledge to make judgments of the effectiveness of scientific applications. Thus, the teaching of chemistry has to empower students to make such judgments and to allow them to recognize the types of scientific knowledge that enhance and hinder social development. As was
discussed in Chapter 3, the negative image of chemistry which is so effectively embedded in the minds of society is a consequence of media exposure and emphasis of ‘events’ which have a chemistry connection, such as oil-spills, natural gas explosions, natural disasters linked to climate change and real and implied threats of chemical warfare.

With respect to the political dimension of chemical education, it is essential that students recognize ways that scientific knowledge and chemical knowledge in particular has been negotiated in the political arena and likewise new chemical discoveries should have the aim of directly benefiting society rather that destroying it and political financial resources should be directed towards supporting the former rather than the latter. Chemical education should empower student to make informed judgments on such issues and, in addition, reflect on the status, role, duty and obligation of private organizations and political power structures which directly influence the scientific culture of a society. Another aspect of the socio-political system is the way in which the global chemical community negotiates and validates new and existing knowledge. It is important for Year 1 students to begin to understand this process. Examples of the way the prestigious societies publish research work illustrates this feature of the scientific enterprise.

Lawton’s economic system is concerned with the distribution of resources. The resources of science ultimately involve scientific knowledge and processes. The generation of these is dependent either directly or indirectly on finance. Finance relies in part on the status which science has in society. The financial structures of science are tied to the internal organizational structures and the external political system. In chemical education terms, Lawton’s economic system translates to recognition of the economic benefits of chemical knowledge and that a chemistry course which emphasizes this should provide a springboard to recognition of a plethora of career opportunities. In this context, it is necessary to include in the course clear indications that careers in fields such as ‘biotechnology’ rely implicitly on ‘chemical knowledge’. ‘Lack of an identifiable career path’ has been quoted in Chapter 3 as being one of the many reasons why science students choose not to study chemistry as a major and hence inclusion of the ‘economic system’ in the Chemistry 1 curriculum positively addresses this deficiency. Further, in the Chemistry 1 course, it is necessary to qualify this assumption by emphasizing that national development depends on a sustainable chemical industry base and the chemical industry needs trained ‘chemists’. Further,
on the broader front, this message needs to be continuously conveyed to politicians in the language which they understand – the chemical industry is one of the major contributors to the GDP and needs to be protected and nurtured. Also, governments need to allocate a greater proportion of the GDP to fund scientific research and chemistry research in particular, in the universities, CSIRO and in the private sector. A ‘growth economy’ is a ‘sustainable economy’ and scientific research is a major contributor to such an ethos. To some extent, the present federal government has recognised this with the release of its ‘Backing Australia’s Ability’ initiatives (McGauran, 2002 and Howard, 2004) and the Australian chemical industry has downsized over the last decade and has become more efficient and cost effective.

Lawton’s communication system has many interpretations. Communication processes vary within scientific communities and have increased in complexity over time. Ziman (2000) has referred to the ‘formal’ and ‘informal’ aspects of the communication system. The former is concerned with scientific communication in journals, reports and conferences whereby research results are disseminated. The latter involves discussions which scientists have with each other. In both cases, communication is achieved using the language of science. The existence of a communication system as a characteristic of science underlies the social nature of scientific processes.

Thus, in a chemistry context, Lawton’s communication system translates to an understanding of the ‘language of chemistry’ and the need for mathematics knowledge in the understanding of chemistry. These are the essentials of chemical literacy and hence inclusion of the communication system in the Chemistry 1 curriculum ensures that students gain knowledge of the language and constructs of chemistry which are the minimum expectations of the course outcomes. Further, it is necessary to emphasize that the ‘speaking of chemistry’ is more than the dissemination of chemical knowledge. It involves visual conceptualization of chemical concepts. Discourse between chemists must generate mental images which are congruent.

Lawton described his rationality system as the ‘science’ of a society and the ‘processes’ of knowledge production. Cross and Price (1992) elaborated on this view ‘as the process of explanation, answering the question ‘why’ in its various meanings’. The knowledge structures of science are directly related to the methodology and philosophy of science and hence to the network of theories which derive therefrom.
Society bases its explanations of the natural world on analogy, metaphor and models and thus science education must reflect these knowledge construction processes and the learners must be made aware of the processes by which scientific knowledge is accumulated. The rationality system translates to promotion of rational thought by Chemistry 1 students and correlates with the contemporary paradigms of learning that students become ‘thinkers’, ‘discoverers’ and ‘constructors’. These are the means by which students achieve scientific literacy and rely on a ‘student-centred’ learning pedagogy for the Chemistry 1 course. Inclusion therefore of the rationality system in the Chemistry 1 curriculum framework means that emphasis is placed on ‘rational thought and action’ as being implicit in ‘what chemists do’ and how they solve problems confronting society.

Lawton (1998) recognised ‘technology’ as an autonomous field that is coequal to a branch of science but not subordinate to it. There is uniqueness, he argued, about technological knowledge that is characterized by its structural orientation to concrete praxis. He recognised sharp distinctions between both the constructive and contextual values of science and technology. Technology is so fundamentally linked to human and social behaviour that Lawton saw a moral component as an essential element of the curriculum of technology education.

Thus, Lawton’s technology system recognizes that ‘technology’ and science education are inextricably linked. Chemical education therefore must reveal not only how to use technology in chemistry but how appropriate technology is selected. It is important to connect the wide range of so-called ‘high-tech’ advances to chemistry development if chemistry is to continue to be regarded as an ‘enabling science’. Technology must be exploited to enable the development of chemistry and not vice-versa.

A contemporary example of the former is the synergy between nanotechnology and nanochemistry. Chemistry is the synthesis of ‘new matter’ and nanotechnology is simply the creation of organised molecular structures on the scale of nanometers. One of the primary objectives of nanotechnology is ‘information processing’ on the molecular and supramolecular scale leading to the new science of ‘chemionics’. However, Lawton’s ‘technology system’ is the basis of the knowledge transmission process from ‘chemistry’ to ‘chemionics’ or, in more simple terms, from the ‘basic’ to the ‘complex’. Thus, the technology system enables the development and transmission of chemical knowledge.
Chemical education at the tertiary Year 1 level needs to apply the Lawton technology system to show how many new scientific technologies such as biotechnology and nanotechnology have a fundamental basis in chemistry and that development of these technologies is based on the systematic application of chemical knowledge. The technology system in chemical education also enables students to transform their acquired chemical knowledge into technological applications which enhance scientific knowledge to the benefit of society.

The existence of an ethics dimension within science can be understood in terms of Lawton’s morality system which he defined as recognition of ‘a code of behaviour and distinctions between right and wrong’ (Lawton, 1989). Lawton believes that the morality system is an essential element of a society. In a scientific context, it is often the incidences of breach of the scientific moral code which have demonstrated the degree to which the morality of chemistry is challenged by society in its critique of (chemical) weapons of mass destruction, nuclear energy, radioactivity and chemical pollution of the environment.

In relating the Lawton morality system to chemical education, it is necessary to give a balanced view of the role of chemicals in the environment. For example, oil leaks from tankers inflict damage to the environment and particularly to wild-life but chemicals also ‘clean-up’ such oil spills. Similarly, uncontrolled radioactivity as in a nuclear explosion causes enormous damage to the environment and maims humans but controlled radioactivity in the form of nuclear medicine provides enormous benefits to society.

Thus, the Lawton morality system should be a natural inclusion in the Chemistry 1 course curriculum as ethics is embedded in scientific enterprise. The connection between chemical ethics and the public image of chemistry cannot be overlooked since breaches of the scientific moral code are seized upon by the media to expose the negativity of science. This type of media sensationalism is directly related to the widespread image of chemistry as being the cause of many of the problems of the world and being detached from daily life. Thus, the morality system should be a critical pervasive theme of the Chemistry 1 curriculum in order to address this acute widespread misconception and thereby allow student to make informed judgments about the merits or demerits of chemical ethics.

Belief is a fundamental characteristic of science and is in evidence in a range of ways. In a wider context, it can be thought of as the paradigms described by Kuhn
(1970) or the research paradigms of Lakatos (1970). These refer to the way in which the scientific enterprise is conducted and the framework within which scientists work. Such underlying operating principles are one aspect of a belief dimension in science. Ziman (2000) has described science as ‘a general system of beliefs’. Scientists judge scientific results on the basis of their ‘credibility’ and scientific knowledge is developed on the basis of credible (believable) scientific data. Credible scientific data are obtained from experimental data in accordance with the ‘scientific method’ of accumulating knowledge.

The language of Lawton is best used to explain his belief system. Chemistry students should be exposed to the ‘organised scepticism’ concept – the suspension of ‘belief’ until evidence is provided that qualifies the ‘rightness’ of what is being taught. Inclusion of the belief system in the Chemistry 1 curriculum therefore addresses the concerns of McColl (2002) and Schwab (1964) that scientific laws and theories must not be taught as ‘absolute truths’ and that scientific knowledge is not infallible. Thus, the belief system can be applied unilaterally across the Chemistry 1 curriculum and students are left to make judgments of the credibility of the concepts, theories, laws and models which constitute chemical knowledge. For example, two different theories are usually presented at the Chemistry 1 level to explain how molecules are created from atoms. These are the Valence Bond Theory and the Molecular Orbital Theory. Both theories lead to the same conclusion but the pathway to the conclusion differs because each theory is based on different principles. The credibility of each theory is based on the ‘belief’ in electrons and their energy characteristics and thus these two theories of ‘chemical bonding’ are based on the same belief system with each representing a different manifestation of it.

Chemical education therefore must create and nurture ‘belief systems’ in chemistry in order to achieve student chemical literacy through transmission of credible chemical knowledge and at the same time, nurture students’ scepticism. They should be encouraged to evaluate the evidence.

Lawton’s explanation of his ‘aesthetic system’ of a society referred to the standards which apply to judge its ‘quality’. In a scientific culture, the aesthetic system translates into the ‘beauty and wonder of science’ in both its physical and intellectual manifestations. It is the ‘beauty and wonder of chemistry’ that is lacking in senior school chemistry curricula and in the tertiary Chemistry 1 course and this is believed by Chemistry Heads of Department to be a major contributor to the declining
student demand for chemistry study at the tertiary level, as discussed in Chapter 2. The aesthetic value of chemistry is summed up by Atkins (2002) that ‘well-taught chemistry reveals the beauty of chemistry’. There is a powerful message implicit in this statement – that chemistry is not only ‘interesting’ but intrinsically ‘exciting’ and that ‘chemistry is made up of a few simple ideas’. These are attractive forces for students to study chemistry in view of its aesthetic appeal and hence the aesthetic system is a crucial one for inclusion in the Chemistry 1 curriculum. There are many ways in which this can be done but to reveal the beauty of chemistry it is necessary to teach chemistry at the molecular level. Atkins (2003) has shown why this is so:

*The replacement of one or two atoms (in a molecule) can convert*

*a fuel into a poison, change a colour, render an inedible substance*  
edible or replace a pungent odour with a fragrant one.  

(p.1,2)

In this context, Atkins quotes ‘the difference of only one hydrogen atom between the molecules responsible for the blue colour of cornflowers and the red colour of poppies’. Similarly, the male and female sex hormones, testosterone and oestradiol are closely related molecular structures with the former differing from the latter by a single methyl group. The ‘beauty of chemistry’ is related to the structure and behaviour of molecules. It also manifests itself in the architecture of molecules and the diverse ways, some more elegant than others, in which complex molecules can be constructed from a series of simple chemical reactions. Chemistry is a ‘beautiful science’ and chemical education must regard Lawton’s aesthetic system as one of its most important components.

Lawton described his ‘maturation system’ in terms of the ‘maturity of the education system in contributing to social literacy’. The maturity system is easy to interpret in terms of chemistry but perhaps the most difficult system to include in a chemistry course curriculum. It cannot be denied that chemistry is a mature science. It has a rich historical development, it enables many other sciences, particularly the biological sciences and it is at the forefront of new technologies such as the bio- and nano-technologies. However, students often correlate ‘maturation’ with ‘complete’ and ask ‘What more needs to be known in Chemistry’. This leads to ‘Why do I need to study chemistry when I really want to study biology?’ Hence, in including the maturation system in the Chemistry 1 curriculum, it is necessary to apply caution and to explain that it is because chemistry is a mature science, it is the ‘central science’ and provides an indispensable platform for other ‘less mature’ sciences.
Fundamentally, the maturity of chemistry is directly related to its unique ability to define the structure and behaviour of matter at the molecular level. The emerging sciences of ‘genetic manipulation’ and ‘bio-technology’, for example, rely on this defining and enabling feature of chemistry.

However, the maturation system is less easy to interpret in terms of chemical education – at least in an Australian context. It is apparent from the concerns of Chemistry Department Heads on the Chemistry 1 course (see Chapter 2) and the general lack of chemical education research in Australian universities (see Chapter 3) that chemical education in Australian universities lacks maturity and is not transmitting sufficient chemical knowledge for students to achieve chemical literacy upon completion of the first year chemistry course. It appears that the Lawton maturation system is in effect a combination and a culmination of all his other systems and hence the effectiveness of its inclusion in a chemistry course curriculum is dependent on the effectiveness of inclusion of the other systems.

Having described Lawton’s systems in ‘chemical terms’, it is relatively straightforward to show how these systems directly relate to the topics included in the proposed Chemistry 1 curriculum. To illustrate this, one topic is selected from each of the Sections of the curriculum – the structures of which are given in Figures 7.3, 7.4 and 7.5 and the correlations with each of these sections with Lawton’s systems are shown schematically in Figure 7.6 and tabulated below in Table 7.2.
Table 7.2 Correlations of Lawton’s systems with the proposed Chemistry 1 curriculum framework

<table>
<thead>
<tr>
<th>Selected chemistry topic and possible associated Lawton’s system</th>
<th>Chemistry – Lawton Connectivity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Section 1 : Molecules</strong></td>
<td><strong>• Manufactured chemicals have a social-political rationale - sociological - benefit society via enhanced standard of living: political – chemicals contribute to the GDP and export market.</strong></td>
</tr>
<tr>
<td><strong>• Socio-political</strong></td>
<td><strong>• Chemicals in agriculture: sociological – increased food productivity: political: toxicity of pesticides, soil pollution, organic food dilemma.</strong></td>
</tr>
<tr>
<td></td>
<td><strong>• Chemicals in food: sociological – artificial flavours, food preservatives/additives, food nutrition enrichment: political – ingredients in synthetic foods must be stated, GST on foodstuffs debate, food hygiene standards, the vitamins debate/pharmaceutical benefits scheme, beer/liquor tax.</strong></td>
</tr>
<tr>
<td></td>
<td><strong>• Chemicals in textiles and clothing: sociological – synthetic fibres, cheap clothing, dyes and fashion: political – protective clothing in work-safe practice.</strong></td>
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<tr>
<td></td>
<td><strong>• Political: chemistry and health: sociological – pharmaceuticals,</strong></td>
</tr>
<tr>
<td>Economic</td>
<td>antibiotics: political – illicit drugs.</td>
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<td>------------------------------------------------------------------------</td>
<td>----------------------------------------</td>
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<tr>
<td>Chemistry and warfare:</td>
<td></td>
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<tr>
<td>sociological – nuclear weapons, chemical weapons of mass destruction: political – protection devices (star wars), peaceful uses of chemical weapons such as nuclear energy.</td>
<td></td>
</tr>
<tr>
<td>Polymer chemistry: sociological – the plastic age, vast range of useful synthetic polymers in daily life: – pollution of the environment by plastics, education on the use of alternatives and appropriate disposal.</td>
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</tr>
<tr>
<td>All manufactured chemicals have economic significance since earliest times – salt/salary. Fuel oils, pharmaceuticals, pesticides, food preservatives, detergents etc are all an integral part of consumer chemistry.</td>
<td></td>
</tr>
<tr>
<td>The language of chemistry has the ‘grammar’ of atoms and molecules. Food preservatives must be stated to placate public concern over genetically modified foodstuffs.</td>
<td></td>
</tr>
<tr>
<td>Chemists involvement in rational debate on issues such as the effect of chemicals in the environment, dilution of fuel oils with ethanol,</td>
<td></td>
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</tbody>
</table>
- **Technology**
  - Effect of excess carbon dioxide in the atmosphere.
  - Chemists and technology are synonymous terms – synthetic polymers, fade-resistant paints, high octane fuels, pharmaceuticals, pesticides etc.

- **Morality**
  - Chemical ethics – genetically modified foodstuffs, green chemistry, environmentally-friendly or clean chemicals, alternative fuels, greenhouse debate.

- **Belief**
  - Behaviour and function of molecules is directly related to their structure – Atkins ‘good chemistry teaching is able to make students visualize at the macro-level but think at the micro-level’.

- **Aesthetic**

- **Maturation**
  - Chemistry is a socially-aware science, it strives to make molecules which directly enhance standard of living and human longevity and well-being.

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### Section 2: Chemical Modelling

- **Economic**
  - Chemical modelling in the chemical industry is used not only to model every stage of a chemical’s manufacture but also to undertake a cost-benefit
<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td><strong>Communication</strong></td>
<td>analysis of the process to ensure a profit margin.</td>
</tr>
<tr>
<td><strong>Rationality</strong></td>
<td>The full significance of a chemical model is only apparent if those who use it are able to communicate effectively in the language of chemistry.</td>
</tr>
<tr>
<td><strong>Technology</strong></td>
<td>Rational thought on the part of those who construct chemical models and those who use them to understand chemical phenomena. Chemical modelling teaches students to rationally think in chemical terms.</td>
</tr>
<tr>
<td><strong>Belief</strong></td>
<td>Emerging technologies such as nanotechnology derive from chemical modelling of the ways in which molecules interact to form new forms of matter under controlled conditions.</td>
</tr>
<tr>
<td></td>
<td>By referring to models of chemical phenomena, students are able to derive their own individual belief systems since their beliefs and assumptions can be verified by their assumptions of the models used.</td>
</tr>
</tbody>
</table>
### Section 3: Green Chemistry

- Socio-political
- Economic
- Rationality
- Technology
- Morality
- Belief
- Aesthetics

### All are implicit in the basic guiding philosophy of Green Chemistry which is concerned with the production of clean chemicals and their ultimate disposal safely in the environment. The teaching of green chemistry reveals not only the enabling virtues of chemistry but also the ‘user-friendly’ and ‘environmentally-friendly’ nature of chemistry together with its economic, technological, ethical and aesthetic ethos. Green Chemistry is an emerging science which is and will continue to be embraced by the chemical industry as a critical part of its future philosophy.

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#### 7.3.3 Assimilation of Fensham’s social responsibility of science philosophy into the proposed Chemistry 1 curriculum framework

The third stage of development of a new curriculum framework for the Chemistry 1 course involves ‘overlaying’ Fensham’s ‘social responsibility of science’ philosophy on the primary curriculum structure. This philosophy was discussed in detail in Chapter 3 and is characterized by ‘science has to be socially meaningful’ and ‘a science for all approach is necessary if society is to understand the complexities of their environment from an informed viewpoint’. The successful inclusion of these ideas into a chemistry curriculum framework is manifested in students (not the teachers) being able to examine the evidence and being able to make judgments as to whether a particular chemical product or process is socially responsible. In order to achieve this, Chambers (1990) has identified an essential feature of science education:
Science is a way of knowing, which is in certain respects, unlike other ways of knowing. While some forms of knowledge are highly personal and intuitive, the methods of science are designed to be as objective and impersonal as possible. Science has been called 'public knowledge', as opposed to private knowledge because its procedures for verification involve a whole community of scholars, indeed, theoretically involve the whole of society. Science has been called 'organized knowledge', because it is systematic and because it is supported by a group of social institutions without which it could not exist in its modern form. (p.5)

Hoffman (2000) has revealed the inextricable link between chemistry and society:

One defining aspect of human beings has always been the meld of mind and hands in transforming matter. (p.ix)

and:

People want to change the natural world into the useful un-natural. To add value is to profit. However, the moral tenor of this age demands that whatever we transform be done with social justice and with respect for nature. (p.xi)

and:

The same nicely obsessive penchant for control such as that used to make molecules do acrobatics can and is being turned to the attainment of a necessary balance between our given imperative to create and our love of the world. (p.xi)

The social responsibility of chemistry is in effect a balance between its social benefits and its social harms and students need to make their own judgments as to where the balance lies if they are to understand the significance of chemistry as a socially responsible science. This is emphasized by White (1996):

The type of science that is taught is one factor that determines peoples’ attitudes to science and their choosing to study or to avoid it. Others are the image of science that is transmitted throughout society and the personal experiences of the student. (p.123)
It is now appropriate to discuss how Fensham’s social responsibility of science philosophy can be merged with the chemistry content of the proposed curriculum framework for the Chemistry 1 course and this is effected by means of Table 7.3 below.

<table>
<thead>
<tr>
<th>SELECTED CHEMISTRY TOPIC AND POSSIBLE SOCIOLOGICAL ASSOCIATIONS</th>
<th>CHEMISTRY – FENSHAM CONNECTIVITY</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Section 1:</strong></td>
<td></td>
</tr>
<tr>
<td>• Energy Conservation</td>
<td>• Conservation of fossil fuels and the necessary community educational process. The ‘greenhouse gas’ debate and linking of social justice and injustice with respect to carbon dioxide emissions, the Kyoto Accord and the consequences of international compliance not achieved.</td>
</tr>
<tr>
<td></td>
<td>• The political dimension of ‘energy’ and the economic consequences on society of the fuel tax. The apparent political correlation of the price of fuel oils to supply as controlled by the global oil barons.</td>
</tr>
<tr>
<td>• The element Chlorine</td>
<td>• Pesticides in agriculture – the DDT controversy (thalidomide) – banning of DDT has led to proliferation of malaria globally. The ‘organic agriculture’ debate – cannot ‘feed the world’. The GM</td>
</tr>
</tbody>
</table>
debate – pest resistant strains of corn etc but belief that genetic modification of foodstuffs is immoral.

- Chlorine as the primary agent for the sterilization of drinking water – WHO’s attempts to educate the developing world on the illumination of water-borne diseases.
- Chlorine and its use in chemical weapons – the social justice debate.

<table>
<thead>
<tr>
<th>Section 2:</th>
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<tr>
<td><strong>Drugs</strong></td>
</tr>
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</table>

- Two categories – the socially acceptable (pharmaceuticals) and the socially unacceptable (drugs of addiction). The natural therapies debate – ‘natural is better’. Drug overdose/social justice issues, ‘performance enhancement drugs’ in sport/controversial expulsions. ‘Bad drugs’ are not entirely ‘bad’ – morphine is still the best known agent for control of pain. Oral contraceptives and chemists’ contribution to women’s liberty-ethical issues such as IVF and fertility control – ‘Viagra’. The increasing dependence of societies in the developed world on pharmaceuticals and the corresponding lack of these in the developing world. Major life-threatening diseases such as malaria, have been eradicated in
the developed world but are still prevalent in the developing world – the role of chemistry in bridging this divide.

**Section 3:**

- **Forensic Chemistry**


- **The chemical industry**

  [Polymer industry is the largest chemical industry]

  - Plastics are cheap and dominate our way of life. Plastics are used in modern surgery – artificial organs. Plastic substitutes for wood and fibres are common – furniture and carpets etc. Plastics are vital in food storage and in construction since they can be moulded into any shape. However, plastics take some 15 years to degrade in the environment, contain toxic components and burn with the
release of toxic fumes – leading to pollution of the environment. The ‘plastic disposal’ education debate – recycle, re-use, remove.

- Adoption by the chemical industry of the principles of ‘green chemistry’ – changing image of the chemical industry – social responsibility of the chemical industry – green technology is clean technology – chemistry recognizing its social and environmental responsibilities – chemistry supports green technology. Chemistry recognizes its social and environmental responsibilities.

A diagram showing this assimilation is given in Figure 7.7.
Thus, the overall proposed curriculum framework for the Chemistry 1 course has been developed in several phases – the first uses the generic curriculum framework proposed by Lawton, the second builds the chemical content of the curriculum based on Atkins’s 9 basic principles of chemistry, the third overlays the basic structure with Lawton’s ‘systems’ and the final phase further overlays the curriculum with ‘Fensham’s ‘social responsibility of science’ philosophy. This proposed curriculum framework is shown in Figure 7.8.

7.4 CONCLUSION

A new curriculum framework for the Chemistry 1 course has been developed based on a set of principles which encompass three contemporary educational philosophies: Lawton’s ‘systems’, Atkins ‘simple structure of chemistry’ and Fensham’s ‘social responsibility of science’. The proposed framework also embraces principles of learning and teaching of chemistry at the tertiary level based on developments in chemical education in Australia and internationally over the past decade. The framework is also informed by the concerns over the structure of the Chemistry 1 course in Australian universities as revealed by Heads of chemistry departments (see Chapter 2) and the constraints identified by them (see Chapter 5) which are impeding change to the present structure. This is most apparent from the new approach which has been applied to curriculum design – based on a set of guiding principles and informed by three contemporary educational theories which
lead to a framework for teaching chemistry at the tertiary level. The learning outcomes include equipping students with chemical knowledge not only to sustain and enrich their pre-selected scientific careers but also to provide them with a foundation level of chemical literacy to enhance the scientific literacy of society overall.

In addition to changes in content, the proposed curriculum framework implies changes to practical work associated with the Chemistry 1 course. The many constraints on chemistry practical work (see Chapter 5) have meant that the number of laboratory exercise in the Chemistry 1 course has been progressively reduced despite the recognition that practical work is in general one of the most enjoyable aspects of the course and routinely receives positive student feedback. The laboratory exercises associated with the proposed curriculum framework needs to reveal the ‘context’ and ‘social’ dimensions of chemistry, particularly by involving the use of ‘environmentally-friendly’ chemicals and embracing the principles of ‘green chemistry’ holistically. Also, rather than using the basic analytical techniques, such as ‘titrations’ and ‘gravimetric analysis’, analytical techniques which are used in chemical industry R&D laboratories, forensic laboratories and CSIRO laboratories, should be introduced. The spectroscopic techniques such as UV-Visible spectroscopy and infrared spectroscopy are important in this context.

The proposed curriculum framework also implies extensive use of IT in learning and teaching methodologies, particularly in the development of self-paced problem-solving skills and modelling (animation) of chemical phenomena.

It has been recognized throughout this project that a major task confronting tertiary chemistry education at the Year 1 level is to provide a chemistry curriculum that serves the needs of all students in terms of scientific and technological literacy and at the same time provides for some students who aspire to further their science studies in the chemical sciences. It is believed that the curriculum framework presented here not only satisfies this need but also has a wide variety of other attributes. It is a unified, integrated, inclusive and flexible curriculum in terms of the content. It embraces new paradigms of teaching and learning and focuses on the quality of the learning via a ‘student-centred’ learning approach. It also links chemical education with technological education, a further aspect of ‘science education’ promoted by Fensham (1996):
Now that these two very powerful areas of human thought (science and technology education) and societal life co-exist as major contenders for student attention in post-compulsory education, it can be expected that a number of established assumptions and practices about science in education will be challenged in the next few years of Australian education. (p.317)

The proposed curriculum is based on contemporary education theory and it has a strong emphasis on the essential ‘elements’ which constitute ‘transferable knowledge’ and on the social responsibility of chemistry. It is consistent with ‘the essential features of a contemporary curriculum’ as proposed by Smith and Lovat (2003):

A viable future (for education) must be based on a curriculum that recognizes the inherent integration of science and the natural links of humans to something greater than their own individual identity and emphasizes the importance of creating both an individual and a global reality through the power of positive mental imaging. Such a curriculum is one concerned not just with the ‘facts’ of information nor only with the meanings behind those facts but with instilling critical reflection leading to praxis that practical action on reflection which is orientated to change, change for the betterment of self, the betterment of others and the world. (p.241/2)

The effectiveness of the proposed curriculum for Chemistry 1 is assessed in Chapter 8 by selecting one of the topics for a detailed analysis of content and superimposition of Lawton’s ‘systems’ and Fensham’s ‘social responsibility of science’ philosophy. It is the integration of the individual premises of the curriculum which verify its credibility as a viable contemporary curriculum for Chemistry 1.

BIBLIOGRAPHY


CHAPTER 8
CHEMICAL THERMODYNAMICS AS AN EXAMPLE OF A NEW CHEMISTRY 1 CURRICULUM

8.1 INTRODUCTION

The purpose of this chapter is to select one of the chemistry topics proposed in the new Chemistry 1 curriculum framework discussed in detail in Chapter 7 for detailed curriculum analysis in terms of the principles underlying its construction. In particular, Lawton’s ‘systems’, Atkins’ ‘simplicity of chemistry’ and Fensham’s ‘social responsibility of science’ philosophies which together form the basis of the curriculum reform process also differentiate this reform from previous attempts. The topic chosen for such detailed discussion is ‘chemical thermodynamics’. This topic was selected not only because this is generally regarded by students as the least appealing of all chemistry topics because of its perceived obscurity but because it is one of the most challenging topics to teach and it is the author’s specialist field of research. It was apparent from the structures of the Chemistry 1 course reviewed as part of the interviews with Chemistry Heads of Departments (see Chapter 2) that most adopted the traditional approach to teaching chemical thermodynamics at the Year 1 level. A notable exception was the approach adopted by the University of Adelaide which has applied the ‘context-based’ and ‘problem-based’ methodologies to the teaching of chemical thermodynamics in Chemistry 1. Therefore, the traditional approaches and the Adelaide approach with respect to chemical thermodynamics component of the Chemistry 1 course are compared with the new approach proposed in Chapter 7 with is based on an assimilation of three contemporary educational philosophies.

The scope of this chapter is to confine the curriculum analysis and discussion to chemical thermodynamics – as encompassed by the ‘First and Second Laws’. In the proposed curriculum framework for Chemistry 1, chemical thermodynamics is included in Section 1, ‘Chemistry – The Central Science’, as shown in Fig.7.3 in Chapter 7. The related topics of chemical equilibrium, chemical kinetics and electrochemistry/redox are included as separate sub-sections and are not included in the present discussion, although it is shown how an understanding of chemical
thermodynamics is critically important to an understanding of these three related topics.

The perceived outcome of this chapter is to reveal that the Chemistry 1 curriculum framework proposed in Chapter 7, based on a syntheses of Atkins’ ‘simplicity of chemistry’, Lawton’s ‘systems’ and Fensham’s ‘social responsibility of science’ is effective for developing a new approach to understanding chemical thermodynamics at the tertiary Year 1 level.

8.2 THE TRADITIONAL CONTENT OF THE CHEMICAL THERMODYNAMICS COMPONENT OF THE CHEMISTRY 1 COURSE

The ‘traditional’ (long-standing) structure of the chemical thermodynamics topic in the Chemistry 1 course is essentially based on the first and second laws of thermodynamics and is thus divided into two sections. This structure is essentially consistent with that adopted in the wide range of textbooks devoted to a course in ‘General Chemistry’ and two of these are discussed here to illustrate this feature: ‘Chemistry: Molecules, Matter and Change’, Atkins and Jones (1997), hereafter referred to as ‘A-J’ and ‘Chemistry: The Science in Context’, Gilbert, Kirss and Davies (2004), hereafter referred to as ‘G-K-D’. Both of these texts and many others tend to simplify the concepts of chemical thermodynamics so as to ‘remove the fear factor’ and to increase motivation and interest in the subject. ‘Removing the fear factor’ relates to finding a title for chemical thermodynamics which does not include ‘thermodynamics’ and alternative titles which have emerged are ‘thermochemistry’ and ‘energy dynamics’. As will be discussed in Section 8.3, neither of these titles is appropriate and an alternative title is suggested. Further, there are many shortcomings of the traditional Year 1 chemical thermodynamics and these are highlighted here to further emphasise the need for review and reform of this course.

The traditional approach assumes some previous understanding of ‘energy’ even if this has only come about by a school project using the ‘excellent’ ‘School Project – Energy’ package. This gives a clear ‘easy to understand’ visualisation of ‘energy’ from the sun as its ultimate ‘source’ to the various other sources of energy and the need for all of us to ‘save energy’ illustrated by simple ways that this can be achieved such as ‘using a bicycle’ instead of ‘driving a car’. Thus, the traditional
approach starts with the concept of energy and usually discusses ‘types’ or ‘forms’ of energy such as heat, sound, electrical and radiation, to but name but a few (A-J, p.182, G-K-D, p515). It will be shown in Section 8.3 that this is one of many ‘misconceptions’ in the traditional approach which impact on the students’ understanding of the fundamental concepts of chemical thermodynamics. Energy is placed in context by relating it to ‘heat and work’ and given a social analogy such as a ‘bank of energy’ dealing in two ‘currencies’ – ‘heat’ and ‘work’. This is a good analogy (A-J, p.138). The concept of energy is then linked to chemistry and, in particular, to chemical reactions. Chemical reactions involve a ‘change in energy’ which is manifested as an evolution (exothermic) or absorption (endothermic) of ‘heat’ (A-J, p.184: G-K-D, p.518). A second misconception often intervenes at this point – that ‘exothermic reactions’ are ‘spontaneous reactions’. Although most exothermic reactions are spontaneous, many endothermic reactions are spontaneous also and hence the energy evolved or absorbed by a chemical reaction is not its driving force. This critical distinction is not emphasised in the traditional course. To avoid this misconception, an unambiguous definition of ‘spontaneous change’ is required which does not refer to ‘heat of reaction’.

The everyday context of exothermic reactions is easy to illustrate – fossil fuel combustion leading to internal heating of homes and cars, pyrotechnics and bushfires but it is not so easy to illustrate the everyday context of endothermic chemical reactions. One example that is often used is that chemicals used in refrigerators are ineffective since endothermic reactions in general only have ‘small’ cooling effects. This concept of ‘large’ and ‘small’ heating effects leads naturally to the ‘measurement of energy’ and to the thermodynamic term ‘enthalpy’. It is pointed out that enthalpy can be visualised as the heat evolved or absorbed by a chemical reaction when an ‘environment of constant pressure’ applies (A-J, p.188 – 190, G-D-K, p.523 – 524). In daily experience, the ‘environment of constant pressure’ is ‘atmospheric pressure’. In reality, most chemistry and hence most chemical processes relate to ‘atmospheric pressure’ and hence the somewhat obscure meaning of ‘enthalpy’ is clarified. However, although ‘enthalpy’ quantifies ‘energy’, it is pointed out that only ‘enthalpy changes’ can be measured. Thus, for a chemical reaction, whether exothermic or endothermic, an enthalpy change applies which is quantified in energy units relative to the ‘unit of chemistry’ – the ‘mole’. Thus the energy released or absorbed by a chemical reaction is expressed in the units of ‘joules per mole’. It is this quantifying
of ‘energy’ which is essentially the difference between ‘school chemical thermodynamics’ and ‘university chemical thermodynamics’ and it is a value added step forward in the learning process since it is possible to understand chemistry more completely in terms of ‘enthalpy’ than in terms of ‘energy’ – enthalpy gives added meaning to energy. However, this depends on students having a clear understanding of the term ‘mole’, the unilateral unit of chemistry and that chemical reactions can only be interpreted in terms of the ‘mole’ and not in terms of ‘mass’.

A link with ‘bio-energetics’ and the ‘energetics of the natural world’ is usually made at this point by indicating that the most significant biochemical process is photosynthesis (A-J, p.195) involving the synthesis of carbohydrates from carbon dioxide and water in the presence of sunlight and that physical transformations are also important in the natural world such as the enhanced melting of the polar ice-caps resulting from ‘excess’ greenhouse gases in the atmosphere. This aspect needs to be emphasised in terms of the ‘world’s enthalpy resources’ rather than ‘natural energy resources’ so that ‘conservation of energy’ has quantitative significance on a global scale.

Hess’s Law then follows – that ‘enthalpy changes’ are ‘additive’ (A-J, p.198, G-K-D, p.542) and in an everyday context, application of this law leads to predictions of heat output of fuels, particularly the ‘new fuels’ being derived from the biosphere such as methane. However, students have difficulty with the term ‘additive’ in this context and ‘algebraic addition’ needs to be emphasised as the basis of enthalpy calculations. It is usually pointed out that since there are many types of chemical processes, there are many types of reaction enthalpy. This is an artificial categorisation. One of the most relevant analogies is that although chemical combustion is a very familiar process in daily life, food digestion is in reality a natural biological combustion process, thereby linking ‘food energies’ to diet and fitness. The final part of ‘thermochemistry’ is to take the concept of enthalpy one stage further to ‘standard enthalpies’. Again, in the language of thermodynamics – ‘enthalpy is pressure and temperature dependent’ so it is necessary to standardize the conditions to which an enthalpy value refers. These conditions are internationally agreed and thus tabulated enthalpy data have universal significance. However, it is not usually emphasised that the standardization process is simply a matter of convenience and is not a separate aspect or ‘law’ of thermodynamics, neither are examples given of the intrinsic value of such data. It will be shown Section 8.3 that ‘standard reaction
enthalpies’ are used frequently in the chemical industry to plan the most economic route to the production of chemicals thereby showing the practical use of enthalpy calculations in the financial management of the chemical industry.

The second section of traditional chemical thermodynamics in the Chemistry 1 course is focused around the ‘Second Law’. It is generally assumed that students have not previously been exposed to this concept. Again, it is difficult to teach this part of the course without extensive interpretation of the language of thermodynamics into more simple terms. Thus, in talking about ‘a spontaneous (chemical) change’, this concept is usually introduced as ‘a chemical change which occurs of its own accord without external influence’. It is not easy to place the concept of spontaneity into an everyday context. If we say that a bushfire is a spontaneous event, students will say that bushfires usually arise from ‘lightning strikes’ or are ‘deliberately lit’ and thus ‘bushfires are not spontaneous events’. If bushfires were spontaneous events, they would occur continuously irrespective of prevailing conditions. The dilemma here is that although spontaneous chemical events are common spectacular and familiar, such events are not common in everyday experience. The traditional Year 1 chemical thermodynamics course has considerable difficulty with this concept and suggestions are made in Section 8.3 for overcoming this by offering a more tangible interpretation of this key aspect of the Second Law.

Next, the concept of ‘order’ is introduced and hence the thermodynamic term ‘entropy’ (A-J, p.595, G-K-D, p.616). The simplest expression of the Second Law of Thermodynamics is usually given that ‘the (total) entropy of natural (spontaneous) systems increases’. This implies an understanding of ‘total’ in this context which is the sum of the entropy of the ‘system’ and that of the ‘surroundings’. Thereby numerous opportunities for misunderstanding and confusion arise. Firstly, we need some visual understanding of ‘order’ and of a ‘system’ from the thermodynamic viewpoint. In fact, it is a combination of ‘entropy’ and ‘enthalpy’ which is the driving force of chemical processes and hence the raison d’être for chemical thermodynamics. There are many analogies given in the traditional course to picture ‘order’ or to differentiate ‘order’ from ‘disorder’ in everyday terms such as the ‘teenagers messy bedroom’ (G-K-D, p.671). Entropy is simply a term which quantifies ‘order’ and as with ‘enthalpy’, only ‘changes’ in entropy are relevant in a chemical context. Standard entropies have the same connotation as standard enthalpies.
The next stage is usually to introduce a further ‘thermodynamic term’ – ‘free energy’ (A-J, p.603, G.K.D, p622). This term has major significance in chemistry since it is directly related to ‘enthalpy’ and ‘entropy’ and provides a way of correlating ‘entropy’ with ‘system’. Rarely in the traditional approach to teaching chemical thermodynamics is this feature highlighted and students believe as a result that three thermodynamic terms (enthalpy, entropy and free energy) are necessary to describe the thermodynamic behaviour of a chemical process, whereas in reality, only two such terms are required, enthalpy and entropy. Although ‘entropy’ quantifies ‘spontaneity’ of chemical processes, it is the interpretation of ‘entropy’ which is critical in this correlation. Numerous misconceptions are apparent at this point since it is difficult to interpret the ‘system’ to which the term ‘entropy’ applies. In chemical terms, the ‘system’ is usually a chemical reaction but in using entropy as a means of indicating spontaneity the ‘surroundings’ of the ‘system’ also has to be considered. Thus, in order to determine the spontaneity of a chemical reaction, it is necessary to know the standard entropy change for the reaction and the entropy change for the surroundings. If this ‘total’ entropy change is positive then the reaction is ‘spontaneous’. Put simply, the ‘order’ of the ‘surroundings’ changes by virtue of the reaction producing or absorbing heat and the magnitude of this entropy change is proportional to the heat evolved to or absorbed from the surroundings. It would be more convenient if spontaneity of a chemical reaction could be predicted from a thermodynamic term which relates to the reaction and not to both the reaction and its surroundings. A simple mathematical manipulation allows this to done and hence a new term ‘free energy’ emerges. Then if the ‘free energy change’ for a reaction is negative, the reaction is spontaneous. There is no need to be concerned about the free energy change of the surroundings. This explanation is rarely given in the traditional course. Naturally, there are issues of ‘sign convention’ of thermodynamic terms which have to be addressed but the principal issue is to emphasize that ‘free energy’ is a derived thermodynamic term which comes into being to simplify understanding of ‘spontaneity’ in a chemical context. Finally, the traditional Year 1 chemical thermodynamics course concludes with a correlation of free energy with chemical equilibrium (A-J, p. 730, G-K-D, p. 613) and the effect of temperature on the speed or rate of chemical reactions, which is the topic of chemical kinetics (A-J, p.671, G-K.D, p.670). Both chemical equilibrium and chemical kinetics are usually discussed as
separate topics in a traditional Chemistry 1 course and chemical kinetics is frequently deleted.

The University of Adelaide Chemistry Department has recently restructured its ‘mainstream’ Chemistry 1 course and its ‘Introductory Chemistry 1 course’ (Metha, 2005). There are four major components of the ‘Chemical Thermodynamics’ section: Reaction Energetics, Chemical Equilibrium, Acids & Bases and Reaction Kinetics. The Reaction Energetics section includes ‘energy’, ‘enthalpy’ and ‘free energy’ but with only minor reference to ‘enthalpy’. Hence, the key principles of chemical thermodynamics are covered in this first section of the unit. The Chemical Equilibrium section derives from the discussion of ‘free energy’ in the introductory section and the Acids & Bases section is simply a series of examples of (the most important series) of chemical reactions/chemical equilibria and relating these to illustrate the ‘strengths’ of acids and bases. The final section – ‘Chemical Kinetics’ correlates ‘reaction rate’ with ‘chemical equilibrium’ with particular reference to biochemical reactions. This curriculum framework is still largely ‘traditional’ in that it is based on ‘traditional’ treatments of the major principles of chemical thermodynamics with particular reference to chemical processes and with more emphasis on ‘examples’ than on ‘principles’. The wider significance of chemical thermodynamics from a sociological, technological and environmental perspective is not addressed. Nevertheless, this structure is an improvement on previous and existing traditional structures and it does de-emphasize the mathematical connotations of chemical thermodynamics thereby allowing students to apply the principles of chemical thermodynamics quantitatively to a variety of chemical processes and phenomena. A major difference between the Adelaide approach and the Hill approach is that ‘chemical kinetics’ is not included in the latter curriculum framework and this exclusion is rationalized in Section 8.3. However, the Adelaide approach does adopt a framework of linking thermodynamic principles to important chemical phenomena which have relevance and significance in everyday experience.

To illustrate the difference between the ‘traditional’ and ‘University of Adelaide’ course structures and that proposed by the author, the essential components of the curriculum framework, as it applies to the chemical thermodynamics section of the overall Chemistry 1 course are summarised in Table 8.1.
Table 8.1  Comparisons between the chemical thermodynamics curriculum traditionally adopted in the Chemistry 1 course and that proposed by Hill

<table>
<thead>
<tr>
<th>TRADITIONAL</th>
<th>ADELAIDE</th>
<th>HILL</th>
</tr>
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<tbody>
<tr>
<td>Energy/Heat</td>
<td></td>
<td>Energy</td>
</tr>
<tr>
<td>Exothermic/Endothermic</td>
<td></td>
<td></td>
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<tr>
<td>Enthalpy/Types</td>
<td></td>
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<tr>
<td>Reaction Enthalpies</td>
<td>Reaction Energetics</td>
<td></td>
</tr>
<tr>
<td>Hess’s Law</td>
<td></td>
<td></td>
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<tr>
<td>Standard Formation</td>
<td></td>
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<tr>
<td>Enthalpies</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Systems and Surroundings</td>
<td></td>
<td></td>
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<tr>
<td>Entropy/Disorder</td>
<td></td>
<td>Entropy</td>
</tr>
<tr>
<td>Standard Entropies</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Entropy of system and surroundings.</td>
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<tr>
<td>Free Energy and</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spontaneous Change</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Free Energy and</td>
<td>Chemical Equilibrium</td>
<td></td>
</tr>
<tr>
<td>Equilibrium</td>
<td>Acids &amp; Bases</td>
<td></td>
</tr>
<tr>
<td>Free Energy/Temperature relationship</td>
<td>Chemical Kinetics</td>
<td></td>
</tr>
</tbody>
</table>

In summary, the traditional course is very detailed, overcrowded and poorly connected. The Adelaide course has a more simplified structure, a clearer association of ‘principles’ to ‘examples’ but is still ‘traditional’ in overall content. The Hill course addresses the identified shortcomings of the traditional course, is less crowded in content, has greater clarity of meaning of fundamental thermodynamic principles with an improved connectivity between these and the framework overall reveals enhanced relativity to everyday experience – as discussed in Section 8.3.
8.3 A NEW CHEMICAL THERMODYNAMICS CURRICULUM FOR THE CHEMISTRY 1 COURSE

The limited research into the teaching and learning of chemical thermodynamics, as reviewed by Thomas and Schwenz (1998), Goedhard and Kaper (2002), Holman (1985) and Holman and Pilling (2003) reveals that students have considerable difficulty understanding the fundamental concepts due to the complexity of the language of thermodynamics and the need for application of mathematical skills. It is well-known that students despair over having to ‘learn’ thermodynamics in Chemistry 1. They have difficulty understanding the concepts because of the abstract nature of these and they have difficulty relating these concepts to the real world. Even if they can understand the significance of ‘energy’ in daily life and its influence on world economies, they have difficulty quantifying this abstract notion. Hence, the initial message for the effective teaching and learning of chemical thermodynamics at the Year 1 level is ‘keep it simple’ and ‘remove the mathematical rigor’. As far as manipulations of the laws of thermodynamics are concerned, the mathematics required is essentially that of ‘addition’ and ‘subtraction’. It is true that if the concept of ‘free energy’ is connected to chemical equilibrium, then more complicated mathematical manipulations are required for the understanding of this connection, but in the proposed curriculum, chemical equilibrium is linked to the direction of reaction spontaneity. Aligned with the mathematics of chemical thermodynamics is the issue of ‘units’ of energy, enthalpy and entropy all involving the unit of energy – the Joule and the fundamental unit of chemistry – the mole, the understanding of which requires familiarity with the Standard International System of Units. ‘Units in Chemistry’ is usually included in the ‘preamble’ or opening lecture of the Chemistry 1 course and for chemical thermodynamics, only three units are relevant, the ‘joule’, ‘Kelvin’ and the ‘mole’.

It is essential to be aware of the major misconceptions that prevail in the understanding of chemical thermodynamics. The most significant of these is that most textbooks discuss ‘types of energy’ such as heat, light, sound and electrical, as discussed in Section 8.2. The correct terminology is that ‘energy’ has ‘many manifestations’ such as heat, light, sound and electricity and once this is accepted, it is easy to understand that ‘one manifestation of energy can be converted into another manifestation’ such that there is no loss or gain of energy in the conversion process.
This explains the ‘conservation of energy’ and the First Law of Thermodynamics in simple, easy to understand terms.

A related misconception is ‘energy into’ and ‘energy out of’ a ‘system’. The simplest way to overcome this is to ask students to imagine that they are holding the reaction vessel. Energy ‘into the system’ will mean that their hands feel ‘cold’ and energy ‘out of the system’ will mean that their hands feel ‘warm’.

Another common misconception among students is that ‘energy’ and ‘enthalpy’ are synonymous terms. As previously discussed, ‘enthalpy’ and ‘reaction heat’ correlate only when a constant pressure, usually atmospheric pressure, applies. Of course, most commonly witnessed thermodynamic events take place under atmospheric pressure. However, students need to be aware that thermodynamic events which take place at high altitude or in the ocean depths, the difference between ‘internal energy change’ and ‘enthalpy change’ is significant and this has great significance in the popular sports of mountaineering and scuba-diving.

Students have difficulty with the concept of a ‘spontaneous change’. This is best described as ‘a change which occurs without work being applied’. This clarifies whether combustion is a spontaneous process and whether bushfires occur ‘naturally’. Similarly, the rusting of iron is a spontaneous process because the presence of water is the only external influence necessary to effect the change in the state of the iron.

Students frequently believe that the heat evolved in a chemical reaction is the driving force of the reaction or, alternatively, an exothermic reaction is a spontaneous reaction. Whereas, it is true that the majority of exothermic chemical reactions are spontaneous, many endothermic reactions are also spontaneous and hence, on this basis, enthalpy cannot be the driving force of a chemical reaction. This means that another thermodynamic quantity is related to chemical spontaneity and this pre-empts the notion of ‘entropy’. However, it is difficult to correlate the entropy change of a chemical reaction directly to spontaneity because the entropy change of the surroundings of the reaction has to be taken into account. The concept of ‘free energy’ is simply a device for overcoming this difficulty.

Having noted the principal misconceptions of students and some new ideas for the teaching and learning of chemical thermodynamics, it is now possible to define the proposed curriculum framework for this unit in the Chemistry 1 course.

The new generalized curriculum framework for the Chemistry 1 course planned and discussed in Chapter 7 is based on the amalgamation of three
independent curriculum theories – the Atkins’ ‘simplicity of chemistry’, Lawton’s ‘systems’ for the transmission of knowledge and Fensham’s ‘social responsibility of science’ philosophy. These three structural elements when combined lead to a new way of approaching science education at the tertiary level. The Atkins approach leads to new learning and teaching methodologies of chemistry: Lawton’s systems are fundamental educational elements of any curriculum but all have major significance in science education and Fensham’s philosophy succinctly shows that ‘science’ is a ‘social’ activity and that science education must have a social emphasis. It has been shown in Chapter 7 how these three curriculum theories can be combined to provide a curriculum framework for the Chemistry 1 course and now it is shown here how this framework can be used for the chemical thermodynamics component.

Firstly, it is necessary to proposed a new title for ‘chemical thermodynamics’ since it has already been shown in Section 8.2 that this long-standing title is somewhat ambiguous. A literal translation of chemical thermodynamics is ‘chemical heat flow’ and this leads to the deduction (by students) that it is the ‘reaction heat’ which is the driving force of a chemical process. Reaction heat is only one component of the ‘reaction driving force’ and it is entropy and not enthalpy which is the driving force of chemical processes and of all ‘spontaneous changes’. A more appropriate title is proposed here ‘chemical energetics’ which eliminates any connection between ‘heat’ and ‘process’.

The synthesis of a curriculum framework for ‘chemical energetics’ in terms of the three selected curriculum theories is shown diagrammatically in Figure 8.1.
The content is based on two of Atkins ‘nine simple ideas of chemistry’ – ‘Energy is conserved’ and ‘Energy and matter tend to disperse’ (Atkins, 2002) and hence only four topics are necessary – ‘Energy’, ‘Enthalpy’, ‘Entropy’ and ‘Spontaneity’ which together constitute the science of thermodynamics. ‘Energy’ and ‘entropy’ correspond to ‘heat’ and ‘entropy’ and ‘spontaneous change’ correspond to ‘flow’. It should be noted that ‘free energy’ is not included in this structure since it is interpreted in terms of ‘spontaneity’. The proposed curriculum framework pre-supposes that each of these topics is related directly to chemical phenomena and that the learning and teaching thereof is enabled by the educational theories of Atkins, Lawton and Fensham. These correlations are described in Tables 8.2 and 8.3. Each of the four proposed content topics is discussed in Table 8.2 in terms of the ‘proposed (Hill) approach’ and the ‘traditional approach’ and these are then compared so as to show the advantages of the Hill approach which is based on Atkins’ ‘simple structure of chemistry’ philosophy. Further correlations of the Hill approach with Lawton’s systems and Fensham’s philosophy are shown in Table 8.3. These correlations show how the educational theories of Atkins, Lawton and Fensham when combined form the basis of a new curriculum for chemical energetics at the tertiary level. These three educational theories suggest numerous ways in which chemical energetics can be re-interpreted and re-evaluated so as to allow students to assess the content of the proposed curriculum in terms of social, economic and environmental values and thus the author’s curriculum framework proposal is shown via Tables 8.2 and 8.3 to provide a new pedagogy in the learning and teaching of chemical energetics at the tertiary level.

Table 8.2 Application of Atkins (chemical) education theory to the (tertiary) chemical energetics curriculum

<table>
<thead>
<tr>
<th>TOPIC</th>
<th>HILL APPROACH</th>
<th>TRADITIONAL APPROACH</th>
<th>ADVANTAGES OF HILL APPROACH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>Has many manifestations: chemical energy being one of the</td>
<td>Has many types: one of which is chemical energy.</td>
<td>Adopts an holistic – universal concept of energy. Also emphasizes the</td>
</tr>
<tr>
<td><strong>Entropy</strong></td>
<td>Energy and matter tend to disperse.</td>
<td>Entropy is a measure of the degree of randomness or disorder of a system.</td>
<td>Both are statements of the second law of thermodynamics but the former correlates entropy back to energy and matter and hence with chemistry. Further ‘disperse’ gives a mental image of ‘disorder’.</td>
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<tr>
<td><strong>Spontaneity</strong></td>
<td>A spontaneous chemical reaction is accompanied by a net increase of entropy with respect to all matter associated with it.</td>
<td>A spontaneous chemical reaction is accompanied by a net increase of entropy of the total system.</td>
<td>The former ties spontaneity directly to Atkins’ definition of entropy and hence to a visual manifestation of the second law. The former eliminates the mathematical</td>
</tr>
<tr>
<td>TOPIC (HILL CURRICULUM)</td>
<td>CORRELATIONS WITH LAWTON</td>
<td>CORRELATIONS WITH FENSHAM</td>
<td></td>
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<tr>
<td>------------------------</td>
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<td>--------------------------</td>
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<tr>
<td><strong>Energy</strong></td>
<td><strong>Socio-Political:</strong> The</td>
<td>Manifestations which are</td>
<td></td>
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<tr>
<td></td>
<td>global energy crisis,</td>
<td>familiar in everyday</td>
<td></td>
</tr>
<tr>
<td></td>
<td>‘greenhouse emissions’,</td>
<td>experience – heat, sound,</td>
<td></td>
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<tr>
<td></td>
<td>conservation of energy,</td>
<td>light, electricity and</td>
<td></td>
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<td></td>
<td>renewable energy sources.</td>
<td>the reliance on energy</td>
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</tr>
<tr>
<td><strong>Economic:</strong> Fuel-efficient systems, fuel taxes, energy economy in the chemical industry.</td>
<td>sustain life-style, industry and all living forms.</td>
<td>The need to conserve energy and the need to find new sources of energy – solar, wind etc. The need to conserve energy in the home.</td>
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<tr>
<td><strong>Technology:</strong> New forms of energy – solar, wind etc. Clean fuel technology, catalytic converters.</td>
<td>The need to distribute energy from the ‘haves’ to the ‘have-nots’.</td>
<td>Connection between ‘energy’ and ‘food’ – the engine which fuels the human system. The concern over increasing obesity in the developed world and the emphasis on diet and energy content of foods. Lack of connection between ‘calories’ and</td>
<td></td>
</tr>
<tr>
<td><strong>Morality:</strong> Pollution of the atmosphere by fuel combustion. CFC’s and ozone depletion. Ethanol substitution in petrol.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Belief:</strong> Electricity is a ‘cleaner/better’ fuel than gas.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Aesthetic:</strong> The benefits of clean fuels – electricity versus gas central heating. Environmental pollution, excess carbon dioxide</td>
<td></td>
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</tbody>
</table>
| **Enthalpy** | **Political:** The political power wielded by oil-rich nations. High tax placed on fuel oils by governments worldwide.  
**Economic:** Thermal accounting in the home and in industry.  
**Technology:** Enthalpy calculations are used to produce chemicals by the most economic and efficient route using the least amount of energy.  
**Belief:** Enthalpy is simply a way of quantifying energy. | The world’s enthalpy resources and the social-political associations.  
‘Oil’ is a major international currency.  
The ‘oil wars’ in reality are a lust for ‘cheap oil’ by the Western nations. The oil-political agenda affects everybody. |
| | **Entropy** | **Socio-Political:** Entropy is omnipresent in daily life. We are constantly attempting to create ‘order’ out of ‘disorder’ in a myriad of ways at an international, national, political, social, family and personal level. However, this can only be achieved by doing ‘work’ on the ‘disordered’  
Health is usually one of the ‘big-ticket’ items on political agendas along with ‘the economy’ and ‘education’.  
Entropy and health are inextricably linked in that our health is constantly in a state of decline and the ‘order’ of the human system decreases. Much effort and cost is involved |
system, which can be physical, psychological or emotional in nature. Warfare causes physical, political and social disorder of nations and societies. Overcoming the ‘entropy effects’ of warfare involve the enabling features of most of Lawton’s systems, especially the economic, communication, technology, morality and belief systems. In everyday experience, the cynical belief system with respect to entropy is that ‘things can only get worse in our world’. Hence, we are constantly trying to improve our standard of living and quality of life but these come at a high price which only the rich nations of the world can afford. Herein lies the nexus between the ‘haves’ and the ‘have-nots’ and the ever widening gap is the cause of many of the worlds’ problems.

| on restoring health by surgery, prescriptive drugs, exercise, dieting and the so-called natural therapies. Entropy intervention in daily life cannot be prevented but it can be controlled and partially removed through education related to the improvement of living standards and quality of life. Similarly, ‘natural resource management’ is simply control of the un-natural processes – pollution which increase disorder of the environment via sociological, economic and scientific strategic educational policies. |

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Sponteneity

Spontaneous change occurs without an external input of energy – it is a characteristic of all ‘natural’ processes. The human body is constantly in decay via the natural ageing process. Ageing is a spontaneous change.

8.4 CONCLUSION

A new curriculum framework for the Chemistry 1 course has been proposed and discussed in Chapter 7. This framework is an integration of three independent contemporary educational theories: Atkins’ ‘simple structure of chemistry’, Lawton’s ‘systems’ and Fensham’s ‘social responsibility of science’ philosophy. This curriculum framework has been developed systematically by the author and derives from his own research in chemical education and that of others both nationally and internationally.

In this chapter, this new curriculum framework is applied to a selected topic of the Chemistry 1 course – ‘chemical thermodynamics’ which has been re-titled ‘chemical energetics’. The content has been consolidated into four main topics: energy, enthalpy, entropy and spontaneity and the ‘Hill approach’ to teaching these topics is compared with the ‘traditional approach’ and the advantages of the former have been highlighted.

Correlations of each of these four major topics with Lawton’s ‘systems’ and Fensham’s ‘social responsibility of science’ philosophy have been tabulated so as to reveal a new approach to teaching chemical energetics at the tertiary level. Such correlations enable students to make their own assessments of the subject matter and to put this into contexts which are familiar to them, thereby enabling the learning process.

A combination of the educational theories of Atkins, Lawton and Fensham into the Hill framework gives a unique blend of learning and teaching opportunities in
chemistry which can be applied not only to the Chemistry 1 course but also to teaching chemistry courses in general. It has been shown in this chapter how the chemical dynamics exemplar endorses the flexibility, credibility and versatility of the curriculum framework for Chemistry 1 proposed in Chapter 7 and thus converts the ‘theoretical statement’ of this thesis into a ‘practical statement’ which can, in principle, be applied to each part of the overall curriculum.

The particular strengths of the proposed curriculum as compared with the ‘traditional’ curriculum are the simplicity of treatment of a minimum of thermodynamic concepts both from a theoretical and mathematical viewpoint and the liberal integration of Lawton’s ‘systems’ and Fensham’s ‘social responsibility of science’ philosophy. It is believed that the uniqueness of the proposed curriculum is largely due to the careful selection of key topics to define the content and the amplification of these by reference to contemporary educational theories and the belief that all science has a direct responsibility to the community which it serves. Such a curriculum has much integrity and credibility and exemplifies contemporary paradigms of learning.

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conceptions of equilibrium and fundamental thermodynamics’,
CHAPTER 9
CONCLUSION

9.1 OVERVIEW

This study has revealed that the perceived ‘chemistry crisis’ in Australia is in reality a crisis in Australian chemical education. The existing curricula in chemistry at the secondary and tertiary levels are not delivering ‘chemical literacy’ or emphasizing that chemistry is essentially a human endeavour and has a profound social responsibility. In particular, the traditional Chemistry 1 course in Australian universities is not attracting students to chemistry or revealing to them the exciting and rewarding career opportunities available to them when they graduate. This study has focused on reform and radical restructure of the Chemistry 1 curriculum to satisfy the demands of contemporary university students in terms of their learning expectations of chemistry and their enjoyment of the course. A new curriculum framework for the Chemistry 1 course has been proposed which is based on contemporary educational theory and incorporates ‘educational elements’ which are essential for the acquisition of knowledge for a new era. The theoretical framework emphasizes that chemistry like all sciences is a human endeavour and has a social responsibility. In particular, the curriculum is designed to provide all students with an acceptable level of chemical literacy, despite their diverse educational backgrounds. The proposed curriculum is deliberately focused on ‘student-centred-learning’ and accords with contemporary teaching and learning methodologies. The proposed curriculum is flexible in that although essential core topics constitute one-third of the course, the remaining two-thirds offer much scope for inclusion of additional topics and deletion of some of those proposed. Many of these topics lend themselves to mini-projects which students can undertake in groups. The proposed curriculum can be the basis of either a one-semester course or a two-semester course, depending on the perspective of Chemistry 1 held by individual chemistry departments. The reaction to the curriculum has been tested by publication of a skeletal version in the RACI journal ‘Chemistry in Australia’ and the seeking of constructive comments from the professional chemistry community and also by development of a curriculum based on the proposed framework for one of the main topics – chemical thermodynamics. It is believed that the proposed curriculum framework incorporates
contemporary ideas and ideals of chemical education and educational theory which this project has researched and it therefore provides an appropriate basis for the teaching and learning of foundation chemistry at the tertiary level. In particular, the course shows that chemistry is an evolving, enabling and a technological science based on moral, ethical and sociological ideals. It is designed to provide a level of chemical literacy commensurate with the requirements of the profession and to equip students to study science from many perspectives including the sociological perspective.

However, the uniqueness of the course and its radical construct may lead to its acceptance being resisted within the chemistry academic community. The chemical industry may well applaud it and certainly the students should harmonize with its ‘student-centred learning’ focus but the extreme conservatism and a reluctance to accept change, which is still an enshrined doctrine within the academic chemistry fraternity, has to be overcome. If the present crisis in chemistry is to be overcome sooner rather than later, this obstacle to progress must be recognised and removed. Australian tertiary chemical education will be enriched by the adoption of the proposed curriculum framework for the Chemistry 1 course because it adopts the contemporary ideals of the global chemical education philosophy. Research is necessary to test these claims. In the beginning, well constructed research is needed as a pilot study. This should be followed by large scale testing and refinement. Also, new teaching methodologies need to be tested to maximize the potential benefits of the proposed reform.

9.2 RESEARCH QUESTIONS REVISITED

Additional outcomes of this project are revealed by revisiting the major Research Questions cited in Chapter 1 and discussing the extent to which these have been answered together with any additional questions that the research has raised.

Question 1

**How can the curriculum used in Chemistry 1 in Australian universities be reformed to arrest the decline in interest in this enabling science?**
This is the major question of this research and the answer is found in the principal achievement of this project as described in Chapter 7. A new curriculum framework has been proposed for the tertiary Chemistry 1 course since this research has found that there has been no systematic restructuring of the Chemistry 1 curriculum for at least three decades and that Heads of Chemistry Departments in Australian Universities have articulated a range of concerns on the structure of the present – traditional course which relate to the inability of this course to attract and retain students in tertiary chemistry. Many imperatives for change to the traditional Chemistry 1 curriculum have been identified in this research together with a number of constraints which are impeding such change. However, it is clear that the need for change to the present Chemistry 1 curriculum outweighs the present constraints impeding such change and hence the rationale for this research is endorsed.

In designing a new curriculum framework for the Chemistry 1 course, it was necessary to recognize that the framework has to be flexible in terms of depth and breadth of content to allow for differential levels of chemistry knowledge of prospective students and also, it had to have a ‘student – centred learning’ focus. Further, the curriculum framework has to embrace contemporary paradigms of teaching and learning and it has to have clear learning outcomes, the most important of which has to be a level of chemical literacy which forms the foundation of an ability by the student to apply the chemical knowledge to enable study of other sciences and a future career in the teaching and learning of chemistry and chemical technology. Most importantly, the new curriculum framework has to be different in content and style from the existing school certificate chemistry courses and have a broad focus of the value of chemistry to society to be able to increase the demand for tertiary chemistry courses and address the present demise of chemistry in Australia.

This has been achieved by use of three contemporary educational theories in the design of a Chemistry 1 curriculum framework such that the chemical content is related to generic educational principles and interpreted in terms of chemistry having a social responsibility. Thus, it is believed that new paradigms of learning and teaching foundation tertiary chemistry have been proposed and developed.

Question 2

Why is the Chemistry 1 course in Australian universities failing to attract students and, in particular, students who want to study chemistry as their major?
This research has found that Heads of Chemistry Departments tend to correlate lack of demand for tertiary chemistry courses with lack of chemistry stimulation by the school leaving certificate courses and, in particular, an inability of the school Year 11 and 12 courses to reveal the excitement and relevance of chemistry in everyday experience. This research has not probed the merits of Australian school science education at depth at the primary and secondary levels. However, a superficial review of the Victorian CSF for students up to Year 10 has revealed that in general terms it does not deliver on some key features of contemporary chemical education. In particular, the extent to which the VCE chemistry curriculum delivers chemical literacy is debatable and consideration of the social responsibility of chemistry is lacking. However, commendable features of the CSF are that an integrated science curriculum is evident and that science is taught holistically throughout, as is chemistry at the senior school level. A further attribute of the CSF is that experimental (‘hands-on’) skills are emphasized at all levels and there is a liberal infusion of student-centred learning throughout, mostly in the form of student projects. The CSF is endowed with clear statements of ‘learning outcomes’ at all levels and sub-levels and the curriculum is structured so that these can be progressively achieved. New paradigms of teaching and learning appear to be in-built into the CSF and rigid ‘internal’ (school-based) and ‘external’ (Board of Studies-based) assessments apply at the VCE level.

Criticisms of the CSF are numerous but not condemning. It is generally believed among the science teaching profession that the Victorian CSF has great merit in terms of its integrated philosophy and its systematic building of knowledge and development of learning skills throughout the primary and secondary school years. There is general acceptance of the VCE assessment procedures, particularly since the school assessment fraction is significant. There is general belief that the VCE curriculum, whilst still too high in content, is manageable. It is also believed by the science teachers that this curriculum is not specifically directed to the most able students who are likely to succeed into tertiary science study and this is a positive feature. This has been a major criticism of previous Year 11/12 science curricula which it was believed, disproportionately advantaged those students who were destined for tertiary studies. However, this generalist type of VCE curriculum has not met with approval from the tertiary sector which argues that the basic (quantitative) science content has been reduced and thus the VCE course is no longer a reliable pre-
requisite for the study of science at the tertiary level. In broad terms, the practitioners of chemical education across the educational sector believe that whilst the primary and secondary science curriculum is appropriately integrated, there is little integration between the secondary and tertiary science curriculum. This has resulted in the universities being forced to offer ‘bridging courses’ in science, particularly in chemistry and mathematics in order to assist students to bridge the knowledge gap between VCE science and university Year 1 science.

The effectiveness of the Australian primary and secondary science curricula in delivering scientific literacy is a major research project in its own right and thus at this stage it is not possible to qualify the view of Heads of Chemistry Departments that the ‘school chemistry courses’ are to ‘blame’ for the lack of demand for tertiary chemistry courses. This research has revealed a range of factors which contribute to such a lack of demand – some of the more notable are a wide range of choice of tertiary science courses many of which do not stipulate chemistry as a pre-requisite, chemistry perceived as being ‘difficult’ compared with other science courses and the negative public image of chemistry. With respect to the present difficulty of retaining students in chemistry at university, this research has revealed that the principle factor operating here is that chemistry students appear to have difficulty identifying a rewarding career path with a chemistry qualification and a perception that chemistry jobs are poorly paid compared with counterparts in non-scientific professions. Further research is required to identify which of these many factors predominates.

**Question 3**

*What are the factors promoting change to the (traditional) Chemistry 1 course curriculum?*

The major imperatives for change to the Chemistry 1 curriculum were revealed by the interviews with Heads of Chemistry Departments. The most significant of these is that quantitative data accumulated over the last decade reveal a progressive decline in demand for tertiary chemistry courses. Chemistry Department Heads believe that a major restructure of the Chemistry 1 curriculum framework can, in part, address this issue but they were impeded in effecting such a restructure within a climate of severe budgetary constraint.

The Chemistry Department Heads believed that the traditional Chemistry 1 course is not revealing the ‘excitement’ of chemistry and not relating chemistry to everyday experience. It was also recognised that students find chemistry difficult as
compared to the biological sciences and have difficulty with the mathematical concepts essential for understanding the quantitative aspects of chemistry. Thus, in restructuring the Chemistry 1 curriculum, they believed it is necessary to address these perceptions of students and construct a course with a ‘student-learning’ focus. In this context the Heads identified some ‘essential skills’ which must be included in a Chemistry 1 course if such a course was to achieve the major desired outcome of chemical literacy. Heads believed that IT can assist in the development of these skills particularly in the construction of models of chemical phenomena to augment the learning process. This research has found that students are not attracted to tertiary chemistry not only because of the perceived difficulty of the traditional Chemistry 1 course but also because of the perceived lack of relevant practical work and the perceived limited use of information technology both in the teaching and learning process.

Question 4

What is the status of chemical education in Australia and how is this addressing the decline of chemistry nationally and, in particular, the declining student interest in chemistry?

A comprehensive review of the Australian chemical education literature has been undertaken (see Chapter 3) in order not only to answer this question but also to provide a platform of contemporary ideas and ideals upon which to develop the chemical education culture in Australia so as to remedy, at least partially, the current chemistry crisis. Three features of this review are apparent. The first is that the extent of the chemical education literature emerging from Australia is insignificant compared to that emerging from the USA, UK and Europe and this reflects the limited chemical education culture in Australia coupled with a general lack of respect for chemical education research in Australian universities. The second general feature is that the bulk of studies in chemical education relate to the secondary sector and thus chemical education research related to the tertiary sector is very limited. The third general feature is that teaching and learning research in chemistry at the tertiary level in Australian universities is extremely limited and coincidently, much of this has emerged from the Science and Mathematics Education Centre at Curtin University (Treagust, 2002) and the chemical education research group at the University of Western Australia under the direction of Bucat. His paper, ‘The Chemical Education
Enterprise in Australia – A personal view’ published in 2001 encapsulates the frustrations of a low chemical education profile in Australia and the lethargy shown towards its development by the chemistry academic community. Despite this lethargy it is fortunate that the Curtin SME is a world leader in promoting the research-based practice of chemical education and is thus somewhat of a flagship for Australian chemical education. In view of this ‘lethargy towards change’, it is not surprising that the tertiary Chemistry 1 curriculum in Australian universities has remained substantially unchanged for so long and there has been no systematic and consolidated attempts to change it since there has been no momentum to effect change emerging from a chemical education perspective. Since academics tend to characterise their teaching as ‘informed by research’, it follows that Chemistry 1 teaching for many decades has been insufficiently informed by chemical education research and perhaps this is a major reason why the traditional curriculum is so unattractive to students.

**Question 5**

**What is the status of chemical education internationally and particularly in the UK and in the USA and is the demise of chemistry in these regions consistent with that in Australia?**

A thorough review of the international chemical education literature has been undertaken (see Chapter 4) and it is not surprising that much of the focus of chemical education research and assessment is directed to the structure of secondary school chemistry curricula and the effectiveness of these in delivering an appropriate level of chemical literacy. It is apparent that major changes to the secondary chemistry curriculum have taken place in the UK and in Europe with significant success. In this respect, the Salters’ Chemistry Curriculum based on a ‘chemistry in context’ framework has received widespread acclaim both in the UK and in Europe. Whilst there is a considerable international literature on the Year 1 tertiary chemistry course there appears to have been no systematic restructure of this course over at least the past decade. In this respect, Australia is in harmony with the international tertiary chemistry community in resisting significant change to the traditional Chemistry 1 course. However, it is apparent that significant changes have been made to the Chemistry 1 course in the UK as a result of a ‘chemistry crisis’ there in recent years. A determined effort has been made to ensure that the UK Chemistry 1 course is more relevant to everyday experience and is not simply a conglomeration of facts which
have to be learned. The UK chemical education literature gives much insight as to how the traditional chemistry 1 course can be made more interesting for students and engage them more completely in the learning process. It is recognized that the public image of chemistry can only be changed through the medium of education whereby the public makes informed decisions on scientific outcomes. It is most apparent that the professional chemistry societies in the USA, UK, Europe and South East Asia support the teaching and learning of chemistry in a variety of ways to a much greater extent than does the RACI in Australia and this is a significant factor in explaining the limited chemical education culture here.

The most significant proposal emerging from the international chemical education literature is that science teaching at all levels emphasizes its social dimension. It is believed that this is critical if science education is to be equated to scientific literacy. With respect to chemical education, the international literature is emphatic in terms of the criteria which keep students motivated and engaged in the learning process. These relate to the structure of the curriculum and its effectiveness in transmitting chemical knowledge in both a theoretical and practical sense. The former constitutes the fundamentals of chemistry, the latter relates to the use of those fundamentals in advancing technology. However, chemistry has several other dimensions, the ethical, economic and moral dimensions which must be reflected in the teaching and learning of chemistry at all levels. Finally, the international literature emphasizes that chemistry must be taught holistically and that the artificial boundaries of science must be removed if chemistry is to be recognized as an enabling science.

Question 6

What are the constraints impeding change to the Chemistry 1 course curriculum?

Six groups of constraints impeding change to the Chemistry 1 curriculum have been identified and discussed in Chapter 5. These derive from the interviews with Chemistry Department Heads as discussed in Chapter 2. These constraints have been classified in order of manageability in terms of their impact on not only effecting change to the Chemistry 1 curriculum but also to enhancing the status of chemistry in Australian universities and thereby increasing the number of chemistry graduates to meet the demands of the profession. Recommendations have been made to convert ‘constraint’ into ‘opportunity’ to promote progress in an overall climate of declining academic, financial and human resources.
Question 7

How can contemporary educational theories assist in the construction of a new Chemistry 1 curriculum framework?

Three contemporary educational theories have been applied in the design of a new Chemistry 1 curriculum framework. Previous attempts to restructure this course have largely cosmetic and have focused on changes in pedagogy of the chemical content. A new simplified chemical education theory for foundation tertiary chemistry has been used together with a generic educational theory and a ‘social responsibility of science philosophy’. Thus, not only a new curriculum framework has been proposed for the Chemistry 1 course but also a new philosophy of (science) curriculum development has evolved. The proposed curriculum has been informed by contemporary educational theories which have led to embracing contemporary paradigms of chemistry learning and teaching and the clarification of learning outcomes which develop chemical literacy. The key principles of these educational theories have been applied in the development of a new curriculum framework for the foundation tertiary chemistry course in Australian universities and the merits of this framework are an endorsement of these key principles as integral to the development of science education generally.

Question 8

How can such a curriculum framework best be promoted and what are the likely outcomes of its unilateral adoption?

It was apparent from the outset that the chemistry academic community is very conservative and reluctant to accept change, particularly when traditional pedagogies are threatened. However, the imperatives for change to the Chemistry 1 course are of sufficient intensity to effect a softening of this attitude and willingness to trial new approaches to the learning and teaching of foundation tertiary chemistry.

The need for a re-structured tertiary Chemistry 1 course has been indirectly identified by a survey of university chemistry and the chemical industry recently undertaken by the RACI (Gibson, 2005) to quantify the supply/demand nexus of ‘trained chemists’ supporting the sustainability of the chemistry profession. Preliminary data are revealing that ‘demand’ exceeds ‘supply’ which simply endorses the status of chemistry in Australia is declining and this is acting as a deterrent for student to study the discipline.
Realistically, the proposed Chemistry 1 curriculum framework corresponds to a one-semester course in Chemistry at the Year 1 level. It demands new delivery pedagogies and a much wider understanding of the significance of chemistry as a human endeavour. It is not supported by any single textbook or a defined set of laboratory exercises. It will be perceived as a ‘dumbing down’ of the traditional Chemistry 1 course but this argument can be counteracted by the proposed course having a balanced scientific/social premise. Adopting the proposed Chemistry 1 curriculum framework thus challenges traditional academic chemistry ideologies but those who do adopt it will at least be taking a ‘leap of faith’ to address, perhaps in a major way, the declining demand for tertiary chemistry. This, in turn, will be seen as Australian university chemistry addressing the demise of a major enabling science. Perhaps the real test of ‘acceptance’ of the proposed curriculum framework is the publication of specific exemplars of the chemistry topics included therein in order to demonstrate to curriculum implementers how the framework directly enables the learning of chemistry. This has already been attempted with respect to the ‘chemical energetics’ sub-unit, as described in Chapter 8.

9.3 THE FUTURE VISION

It was understood at the outset that simply to focus this project on a restructure of the Chemistry 1 course would not solve the ‘chemistry crisis’ apparent in Australia. However, it is believed that in the process of developing such a curriculum framework, valuable indicators were revealed which collectively can be considered to address the problem. The ultimate solution is essentially in the hands of the chemistry profession and involves a change of mindset towards chemical education and the unassailable forces which are demanding change in the teaching and learning of chemistry in Australian universities. The solution, like the problem is multi-faceted and involves the collective determination of the chemistry profession, the politicians and the general public to accept the centrality of chemistry in the sustainability of the world and the progress of the human race. Nothing less than achievement of this ideal will remedy the present crisis in the long term.
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