Interaction between Industry, Universities and the Professions: Chemistry Courses in English Universities

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Abstract―Major changes in the structure and provision of chemistry courses in English universities have been effected in recent years. The traditional 3-year undergraduate course has been augmented by introduction of a new 4-year course designed explicitly to provide access to postgraduate research training; and formal programmes and educational requirements have been added to the existing research criteria for doctoral courses. The origins of the changes are identified with the social and educational implications of wider access to both the final years of secondary school and to university education. The consequences include concentration of university chemistry courses in the traditional, older universities where a strong research-base is seen to be attractive both academically and financially. Strong historic links between university departments, chemical industry and the chemistry profession have provided key components of these changes.

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1. Introduction

Study of chemistry constitutes a key component of higher education in all developed countries. The universality of its subject matter ensures that courses in chemistry remain recognisably similar, yet there are regional factors that contribute to characteristic national variations in the structure of courses. Cultural, commercial and political factors have all affected the evolution of these variations. In England the effect of these influences has been evident both when courses in chemistry were established in the 19th century and in their development over more recent years.

Chemistry courses in English universities evolved to possess three distinctive characteristics: undergraduate degrees were short; research became a key component; and strong links existed between universities and industry. None of these is unique but in each case the form they adopted reflected national circumstances.

1.1 Undergraduate courses.

By the latter part of the 19th century, three years had become established as an appropriate time for completion of university education both in the reformed ancient universities and in the newly established universities in the industrial cities. Initially this was the time taken to complete a so-called "ordinary" degree; an extended "honours" degree involving specialist study required an extra year. Improvements in secondary education -- raising standards, broadening the curriculum and widening access to the new "grammar schools" - changed this pattern at the start of the 20th century. Larger numbers of well-prepared students entered universities, already able to satisfy the requirements of the preliminary year. They were able to complete a specialised "honours" degree in three years and this rapidly became the standard course in English universities.

The single subject honours degree provided a good format for the study of chemistry. An expanding body of knowledge -- fact, theory, and practice -- could be accommodated within a 3-year course; and provision for advanced special study could be made.[1] The graduates (BSc. or BA) were regarded as well prepared for careers in industry, public service or for further postgraduate study. Even so, the honours degree structure had limitations. Explicitly it did not attempt to provide general education.

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At most, a broader context would be identified by study in depth revealing those economic, social, industrial, and cultural aspects that are central to development of chemistry. Implicitly the transformation, from adolescence to maturity expected in a graduate, resided in non-academic experience and intellectual stimulus shared by staff and students in the numerically small universities.

1.2 Research.

Historically, English universities had been places for teaching, not research. So the significant researches in chemistry 200 years ago were in private laboratories. The Royal Institution, workplace of Davy and Faraday, was both a private research institute and an entertainment centre serving a popular demand for scientific enlightenment. Formation of the Chemical Society (CS), in the 1840's, long pre-dated university departments of chemistry. It was not until the German concept of research-based universities was imported by founding the Royal College of Science (subsequently, Imperial College) in the 1850's that the idea of university chemical research was recognised. By the 1880's the concept of research-based universities had inspired foundation of the new civic universities, notably in Manchester, and allowed creation of research-active chemistry departments. Arguments about the role of research persisted in the ancient universities until the end of the 19th century. Despite this, in the 1880's it was the model of the Royal College that was adopted by Oxford and Cambridge in establishing their departments of chemistry.

The scale of research remained small. It was largely conducted by academic staff, few in number and with fewer assistants. A major change was delayed until the 1920's when industry, government and universities combined to create the modern research department. Once more the inspiration was German in origin, at this time evident from the far greater ability of their chemical industry to meet national needs during the war of 1914-1918. The solution was seen to lie in expansion of postgraduate training in the universities. The means of achieving it were twofold: introduction of an American-style PhD degree as a qualification accessible after 3 years study;[2] and scholarships covering fees and expenses of living, provided through a government agency to students achieving the best honours degrees. Although the level of financial support was not high, it was sufficient to attract students, particularly through the 1930's years of depression.[3] With variants, this scheme of support for research students persists.

1.3 Industry.

As a "useful art" chemistry has provided a base for manufacturing from prehistoric times. It is arguable that creation of a science-based chemical industry in England dates from Perkin's discovery of a method for making aniline dyes.[4] If so, the origin of the modern chemical industry lies in the Royal College of Science. The industry grew rapidly in the remainder of the 19th century though a multiplicity of small firms. The inadequacy of this structure in competition with the far larger American and German companies led to the extensive mergers and acquisitions in the 1920's to create a more economically effective industrial structure.

Both of these phases had significant impact on education in chemistry. As was described above, the latter led to expansion of university research; the former created strong linkages between the universities and industry and established arrangements for accreditation of the professional standards of academic courses. Demand for chemists in the rapidly growing 19th century industry far outstripped the number of university graduates. To fill this need, industry supported part-time evening classes in local colleges. Responsibility for regulating these courses was assigned to the Royal Institute of Chemistry (RIC). This had been established in the 1880's as a statutory body to control the standards of professional chemists. Professors of chemistry in the universities -- who, in accord with their professional status would be senior members of RIC -- with some senior chemists from industry served as examiners for students on the part-time courses. Successful students became graduates of RIC formally with the same status as university graduates. Concurrently, the Chemical Society accredited the chemistry courses in universities. This curious binary system persisted until RIC and CS amalgamated some 30 years ago. Their joint responsibilities for professional standards were then unified in the Royal Society of Chemistry (RSC). By this time, few students attempted to obtain professional qualifications in chemistry other than through a university degree. Equally, universities welcomed the informal linkage to and the formal accreditation of their degrees by RSC as the professional body.[5]

2. The Current Situation - University Reform

Over the past 15 years, the university system in the UK has been transformed. The number of universities and students has doubled, new degree schemes have proliferated, financial constraints have increased, and a regime of assessment and accountability has been established. It would be unreasonable to expect that changes of such magnitude would not cause substantial alteration to provisions for chemistry. There have indeed been significant changes, though perhaps unexpectedly these appear to have strengthened the academic and professional status of courses in chemistry.

For the whole university system the most dramatic change was incorporation of the former polytechnics as full universities in 1992. In England this provided 63 university departments of chemistry, 36 in the "old" universities and

27 in the “new” universities. In itself this did not constitute an increase in chemistry courses or in student numbers: as polytechnics the “new” universities had taught courses for degrees in chemistry under CNAA regulations or for graduate membership of RIC.

The second obvious change has been a huge increase in the number of university students, from 900,000 in 1985 to 1,800,000 in 2001. Numbers of undergraduate students continue to rise at an annual rate of about 1%. These increases do not extend to all subjects. In parallel with other science and engineering subjects, numbers of undergraduate students in chemistry have decreased, currently at an annual rate of about 3% (HESA 2002). Even so, there remain some 12,000 full-time undergraduate students of chemistry. It is notable though that 10 years after the structural change, these students are concentrated in only 36 universities, less than two-thirds of the initial number, and only a small minority of them are “new” universities.

It appears that five student-related factors contribute to this reversion of chemistry courses to the old universities: three of them are external to the universities and affect total numbers; two of them are internal and affect selectivity.

1. *Number of applicants has not increased.* The attraction of chemistry is reduced for school students by the dual impact of the bad public image of “chemicals” and the perception that it is a demanding subject.
2. *Constraints on schools.* Problems in recruiting well qualified science teachers in schools, together with the high cost of providing specialist practical classes for limited numbers of students reduces opportunities for study in secondary schools.
3. *Gender effect.* The large increase in student numbers corresponds to an increase in the proportion of women to over 50%. Chemistry (35%), in common with the other physical sciences (33%) and engineering (11%) attracts a much lower proportion of women students (HESA 2002).
4. *Research.* A higher proportion of chemistry students progresses to postgraduate study than in any other major discipline. From pre-enrolment visits, potential students are well aware that research facilities are better established in the “old” universities than in the “new” universities.
5. *Status and prestige.* The high academic reputation of the old universities continues to influence and attract applicants.

A major additional factor is derived from the quality assessment exercises conducted for English universities. Reviews of departments of chemistry in 1993 (HEFCE, 1995) indicated that, for teaching, all 63 were at least

Table 1 Research Assessments. English Universities --Chemistry

1a Average Research Ratings

Assessment Year	All Universities	Old Universities	New Universities
1992	2.94 (48)	3.69 (33)	1.33 (15)
1996	3.23 (47)	3.94 (33)	1.57 (14)
2001	4.36 (33)	4.55 (29)	3.0 (4)

1b Average Number of Research Active Staff by Research Rating

	Research Rating					
Year	1	2	3	4	5	[5*]
1992	10.9 (10)	11.9 (9)	22.8 (9)	30.2 (12)	38.2 (7)	-
1996	4.6 (7)	10.0 (8)	20.5 (11)	29.4 (11)	42.4 (10)	- (2)
2001	- (0)	- (0)	15.9 (7)	24.9 (9)	39.7 (17)	[49.0] (6)

Notes. **1a** Ratings are on a scale 1 - 5. Level 1 corresponds to a quality below that expected in a university; level 5 corresponds to international excellence in about half of research activity.

1b Excluding Oxford and Cambridge, average numbers of research active staff are 37.1 (1996), 35.6 (2001).In 1996 Oxford and Cambridge were rated 5*. The average of research active staff in these universities in 1996 was 63.5

1a, 1b Tabulated figures in brackets indicate numbers of departments.

"satisfactory".[6] More significance can be attached to the results of the three research assessments (1992, 1996, 2001) (UFC 1992, HEFCE 1996, 2002). The overall ratings for chemistry departments have risen over the 10-year period to an extent closely similar to ratings in other subjects, conforming to a pattern common across the total university system. Two characteristics are evident in the results. First, the research quality ratings for the "old" universities are much higher than those for the "new" universities (**Table 1a**). This is not surprising, as the polytechnics were not funded for research in the same way as the "old" universities. Second, high quality research ratings appear to be associated with larger departments (**Table 1b**). In addition to the institutional status conferred by a high research rating, there is a financial inducement: research subsidy is allocated to universities on the basis of research ratings; there is also good correlation between high ratings and an ability to attract research funds from the research councils, industry and charities. Accordingly, there is a strong incentive for departments to become larger. To do so, departments will seek to attract more students; if the number of students is limited -- as it is in chemistry -- it is to be expected that departments able to do so will emphasise their prestige and research ratings to attract good students.

The combination of these effects has concentrated university provision for chemistry in half the number of departments that existed 10 years ago. The remaining 36 departments are bigger than they were, despite the reduction in total numbers of chemistry students. They are active in research, confirming the traditional link between teaching and research in chemistry; and they are almost entirely contained in the "old" universities -- less than 8% of all chemistry undergraduates are in the "new" universities.

3. Undergraduate Degree Schemes

Survival of departments focussed on the objectives of the historic "elite" function of universities in a system of massified higher education is not unexpected. The need for graduates satisfying the professional requirements of government, industry and commerce remains. It would though be mistaken to infer that the courses provided to meet these objectives remain unchanged. Massified post-compulsory secondary education has itself undergone substantial modification to the extent that assumptions about the preparation of students for university courses have needed revision.

Over recent years, the notoriously specialised curriculum followed by students in the final years of English secondary education has been broadened in an attempt to extend provision of general education. Inevitably, the benefits of these changes are at the expense of reduced preparation in the secondary schools for the specialised subjects of 3-year single honours degrees. Levels of intellectual attainment appropriate for the award of degrees in UK universities are identified by the Quality Assurance Agency (QAA 2001). The QAA does not prescribe course content but does indicate a range within which individual universities and departments should develop diverse courses. Additional constraints are though provided for those courses that need to meet the criteria necessary for entry to the professions and for compatibility with European Union requirements. Some of the professional bodies identify in detail areas of subjects that are expected to be covered in qualifying degree schemes. Currently the RSC does not prescribe any specific content for accreditation of chemistry courses: it does though indicate levels of problem solving ability that should be achieved. It also states that any course failing to satisfy the requirements of QAA would automatically be reviewed (RSC 2001).

For chemistry and other science and engineering subjects in universities, lower standards of preparation provided for school leavers aggravate the problems presented by accretion to their theoretical and knowledge bases, demands for increased professional training and time taken to acquire an appropriate level of intellectual and manipulative skills. One of the few general criticisms of chemistry departments following teaching reviews in the early 1990's was their attempts to include too much detailed material in their courses at the expense of providing a broader perspective (HEFCE 1995).

Constraints of time were identified as limiting opportunities for study in depth of specialised aspects of chemistry, particularly necessary for students who wished to progress to research and postgraduate study. Two alternative solutions were emerged. An official agency, the Office of Science and Technology (OST 1993) recommended that universities should introduce a new one-year qualifying course to be completed before a postgraduate student could be registered for a research degree; this is of course common in other countries. After much discussion, the universities rejected the recommendation. For the physical sciences and engineering, the universities preferred a solution provided by extension of first degree programmes to 4-years. In chemistry, engineering and physics a number of 4-year courses had already been introduced from 1991 and this has now become an accepted pattern. The new 4-year programmes -- identified as "enhanced first degree courses" -- are curiously designated MChem or MSci (Chem) courses (and must not be confused with the postgraduate advanced MSc. degree).

The new courses are additional to, not replacements for the existing 3-year BSc. courses. The two programmes share much common provision: usually years 1 and 2 and much of year 3 are shared by both courses.[7] Both 3- and 4-year courses provide a full chemical education, satisfying the criteria of the Quality Assurance Agency (QAA 2000). The 3-year BSc. courses, while lacking coverage of some detailed specialist areas, continue to serve the needs of students who do not intend to make their careers in research. The courses remain professionally accredited, allow graduates to register as associate members of the RSC and are thought suitable for those intending to enter teaching -- where a fourth-year course will provide a teaching qualification -- the civil service and commerce. It was expected that after the introduction of the new courses any 3-year graduate would need to complete a supplementary qualifying 1-year course before enrolment as a postgraduate research student. In the event, this change has not occurred: at present a graduate with a first class BSc. degree will still be enrolled in most universities for a PhD. and awarded scholarships that cover fees and maintenance.

The 4-year, MChem courses are regarded as more appropriate for those students who seek careers as professional chemists, and especially careers in research. The additional year is largely devoted to project work, usually in association with one of the departmental research groups. Special courses in research methods and in subjects relevant to the area selected by a student for the project are provided in year 3. Despite the financial penalty of an extra year of fees and maintenance costs, the numbers of students choosing the 4-year programme continues to increase, currently at 10% p.a. By 2001, over 40% of chemistry students were enrolled for MChem degrees (RSC 2002). For those students with firm professional ambitions as chemists this is clearly a wise decision: the RSC indicates that an MChem will eventually become a necessary precursor for registration as a Chartered Chemist (CChem). There is though substantial evidence that the additional costs provide a significant disincentive, especially where there remains no effective barrier to enrolment of 3-year graduates as research students.

4. Postgraduate Courses.

Graduate students studying chemistry fall into two categories. The larger group comprises research students, mainly full-time, who follow a largely traditional path to a master's or doctoral degree. The smaller group, perhaps one tenth of the total are those enrolled on full-time or part-time master's courses. The two groups are largely separate in that completion of a master's coursework degree is usually neither a precursor to nor a required component of a research degree.

(a) Coursework Master's Degrees.

Many departments offer these courses. A typical course will last one full year (i.e. 11 or 12 months, not just the academic year) and be divided into two parts. The first part will be devoted to coursework: lectures, seminars and structured laboratory practical work; the second part will be project work either in the laboratory or in an industrial location. Assessment is based on a combination of formal examination, short reports and a more extensive project report. As with all degree courses in English universities, external examiners from other universities and from industry will review the course and scrutinise the work of students to ensure that standards are maintained.

This structure is amenable to study either full-time or part-time. For some part-time courses, the lecture and seminar programme will be concentrated in blocks of time, or presented in the evenings; and the ability to locate projects in industrial laboratories encourages the co-operation of industry.

The courses will in general be identified with a discrete subject area and reflect needs of industry as well as the specialist expertise of the department. Frequently industry provides support through contributions of equipment, to teaching, and through support of employees who are encouraged to enrol. Many students receive support from official agencies with regard to fees.

Both experienced chemists in industry and new graduates enrol in these courses; frequently research students will attend the lectures as part of their programme of formal instruction. Many departments will also provide short courses, mainly directed at chemists employed in local industry or at schoolteachers who need to become familiar with recent developments. In addition to providing an educational service, these courses are expected to generate income for the department and for those teaching the courses.

(b) Research Degrees.

Although aspects of the requirements for research degrees have now been modified, the essential component remains unchanged. This is the submission of a thesis reporting original research of sufficient quality and quantity to conform to the standards expected by the internal and external examiners. In the past there was no requirement to attend or attain a satisfactory standard in any coursework for the simple reason that none was provided: this has now changed (see below). Research students would attend a regular weekly postgraduate lecture or seminar on a research topic. The lectures or seminars would be given by a member of the academic staff or a visitor from another university but they were not connected in theme or structured to constitute a course. A visiting academic from overseas staying for an extended period might well provide a series of lectures on his special subject. There would also be a programme of lectures arranged through the RSC, perhaps one every month through the academic year, open to all members of RSC but presented in the chemistry department. Attendance at these lectures would not be compulsory -- but would be expected for all research students and academic staff.

About 10% of chemistry graduates proceed to study for higher degrees, with a rising proportion, currently almost two-thirds, of them having completed an MChem degree (RSC, 2002). Almost all research students were -- and continue to be -- supported by scholarships. Those with "good" first degrees (now increasingly identified as MChem degrees) would expect to hold scholarships, formally for postgraduate training, from one of the government's Research Councils: these scholarships cover all fees and provide a maintenance allowance lasting for the full 3 years of the normal period expected for a PhD degree.[8] Many departments of chemistry are able to obtain funds from industry, from academic charities (e.g. Welcome Foundation), from endowments and other sources to support research students. Some of these sources are seen to be prestigious and provide rather more generous support to outstanding students; others might be of lower value and be available to students with less good first degrees.

(c) Quality Assurance in the PhD Degree.

General criticism of the standards and status of the PhD degree by commerce, industry, and politicians accumulated in the 1980's. Although the level of criticism varied markedly across different subject areas, the Office of Science and Technology and the Research Councils were commissioned to prepare a discussion paper. This identified 3 areas of concern:

- over-specialisation in PhD programmes, focussing on research topics that were too narrow;
- inadequate personal and professional attainment, especially in regard to communication skills;
- relatively poor quality of some doctoral candidates.

Subsequently, the learned societies and professional bodies undertook reviews in their own specialised areas. RSC published its report in 1995 (RSC 1995). The report noted there was very little active criticism of the current standing of the PhD degree in chemistry. Close relations between academic departments and industry ensured that research training was relevant and that high standards were sustained. Across the whole chemistry profession, it was recognised that the primary purpose of PhD training was to develop independence of thought and the ability to undertake scholarship and research. To this end the existing programmes of study were largely successful in developing investigative skills and broadening the minds, knowledge and experience of students. There were though important secondary objectives, notably in provision of opportunity for students to acquire a range of personal and professional skills that could be improved.

In this context, the RSC identified 5 areas where it was desirable for universities and departments to ensure that research training achieved satisfactory standards.

1. *Broadening the Knowledge-base of graduates.* It had to be recognised that the period of study for PhD constitutes a continuation of the process of higher education. It was expected that completion of a PhD degree in the future would require a total period of 7 years of higher education[9] and that research students would devote about 10% of their time to course work. As guidelines it suggested that students should be able to attend courses relating to their research amounting to about 45 hours tuition (3 hours per week) normally during year 1 of the PhD programme; and to attend regular courses surveying broad aspects of chemistry throughout the 3 years of the PhD programme (equivalent to 1 hour per week). It assumed that attendance at the traditional research seminars and RSC lectures would continue.
2. *Adding to Personal and Professional Skills.* The essence was seen to be a need to improve skills in written and oral communication and in inter-personal relations. It was suggested that all students might be required to prepare regular, written reports on their work. Each year they would write an annual report on their progress, present it formally to the department, and be given an opportunity to defend it orally. Students should expect to present seminar papers, both on their own research area and reviewing other areas of chemistry. Experience of working in a research team and in demonstrating in undergraduate practical classes was identified as a valuable means of developing inter-personal skills.[10]
3. *Supervision.* It is important that all supervisors recognise the need for detailed, time-consuming and intimate supervision. New graduate students require extensive and regular one-to-one supervision if they are to obtain understanding of the appropriate research methodology.

   To assist students and supervisors, the RSC suggested that it would be advantageous for each student to compile a "Postgraduate Skills Record". An appropriate format, comprising a check-list and an individual written record has now been developed by RSC so that each student can identify progress and supervisors and future employers can be aware of the experience accumulated by a student (RSC 2000).
4. *Selection and Assessment.*[11] Supervisors must ensure that students are aware of what is expected of them at all stages of their study. Assessment at the end of year 1 held a special significance. It would be improper for a student whose abilities did not appear to be sufficient to attain the necessary standard to be permitted or encouraged to remain registered for a PhD degree: arrangements for re-registration for a master's degree should be available. Supervisors had responsibility to advise students about the quality of their work at all stages and to ensure that they were fully prepared for submission of their theses at

the end of the period of study.

5. *Institutional Requirements.* Universities needed to ensure that their regulations were in accord with the requirements of the PhD programme. This applied to procedures for registration, progression and assessment of students. The final examination, involving submission and defence of the thesis, required particularly careful regulation. It was recommended and generally accepted that there should be two examiners: an internal examiner who is a member of the department and an external examiner who is an authority on the subject of the thesis; the supervisor should not be an examiner. The examiners needed to assure themselves that the research work satisfied the formal conditions of originality and significance; and that the candidate demonstrated knowledge and understanding appropriate for a professional chemist.

Many of these suggestions had already been implemented in departments of chemistry before the RSC report was published. Broadening the knowledge-base is implicit in the 4-year undergraduate degree scheme designed as a precursor to research study; it is now explicitly part of postgraduate education, usually linked to formal written examinations at the end of year 1. Less than adequate skills in oral communication had been identified as a problem in some QAA reports on undergraduate courses and most departments were well aware of the need to remedy this defect. This and improvements in supervision and assessment are now also addressed in the general requirements for postgraduate training identified in the QAA's Code of Practice for Higher Education and the accompanying Framework for H.E.Qualifications (QAA,1999, 2001). While the RSC and QAA guidelines do not have the force of regulations, their advice clearly identifies an expectation of contractual responsibilities between research students, supervisors and universities. Undoubtedly this is an appropriate contemporary response but it marks a limit to the shared scholarly experience that at one time characterised university research.

5. The Future.

It would be difficult to envisage a modern economy lacking adequate provision for chemistry. Although the traditional characteristics of chemical industry are undergoing major transformation, continuing demand for chemists to serve the needs of industry, the professions and the academic discipline can be assured. To this extent it is appropriate to assume that current levels of output from English universities will be sustained. Even so, it is likely that supply-side changes will see further changes in provisions for chemistry in the universities.

The trend towards fewer and larger departments of chemistry will continue. As an expensive subject with increasing costs both for capital and consumption, economies of scale alone would favour large teaching departments. The linkage between size and research rating, which generates bigger subsidies and support for the larger departments, reinforces these effects. The average number of first-year students admitted to the high-rated (5, 5*) research departments (90) is double that for lower-rated departments (RSC 2002). Already, departments with these high research ratings admit two-thirds of all chemistry degree students and produce three-quarters of all MChem graduates.

Numbers of applicants to universities for courses in engineering and science will continue to decrease. This adds to the problems of smaller departments as those they are able to enrol have generally lower entrance grades than those entering the larger departments. No evidence exists to suggest any foreseeable reversal of this trend. Schools are unable to attract sufficient numbers of good teachers in science and mathematics and are unable to support expensive laboratory classes. Some universities have introduced one-year "preliminary" courses to precede admission to first-year degree studies in engineering and science: as an enabling-science, chemistry provides an important component of these courses. The costs of accepting an educational function formerly exercised by secondary schools may be regarded as an aspect of social provision and so justify additional subsidy to universities. It is less certain that students will perceive the additional intellectual satisfaction of access to an engineering or science degree as justifying an extra year of fees and maintenance costs; there is little evidence that engineering or science graduates achieve enhanced earning capacity.

Some clarification of the purpose of the designation of MChem must also be expected. Although it was identified by the universities as a better alternative than a compulsory pre-doctoral qualifying course, less than a quarter of MChem graduates proceed to a higher degree. In some universities (e.g. Cambridge, Oxford), the MChem is the only degree course in chemistry: in these universities it is a professional degree and is required as a precursor to a research degree, even so, no more than 15% of the graduates proceed to a higher degree. In other universities, there are both 3-year and 4-year degrees; the MChem constitutes the professional degree but is neither a necessary nor a sufficient qualification for registration for a higher degree. Still other universities identify a 4-year degree including one year spent in industry or overseas as MChem: while such programmes clearly enrich the first degree they do not self-evidently provide professional enhancement.[12] All experience suggests that when universities do not themselves clarify such confusion, external bodies will impose solutions.[13]

Remarks

1. Most single-subject honours degrees followed a pattern of requiring students to study three subjects in year 1 (typically, chemistry, physics, mathematics), two in year 2, and one in the final year. Time devoted to chemistry would double in the second year, and occupy all the time in the third year. All chemistry students would be expected to show some competence in German. The University of Oxford was unique: its students were required to study only chemistry and for 4 years, the last year being devoted to a research project; even so, students were expected to pass university "preliminary examinations" in mathematics and physics at some stage in their first year.

2. The existing DSc degrees were (and still are) designed to indicate a high level of achievement by a mature scholar who can demonstrate an impressive volume of published work.

3. Its success was reflected in the assumption, valid until recent years that the terms postgraduate student and research student were synonymous in chemistry.

4. It is though at least arguable that Perkin's discovery of mauveine was far from scientific. He was attempting to synthesise quinine by oxidising a mixture of aniline and toluidines. When pouring the black residue into a stream of water he noticed a brilliant purple coloration on the fringe of the effluent. Perkin's scientific achievement was his ability to pursue this observation with sufficient chemical skills to isolate the dyestuff; his entrepreneurial abilities led him to leave the College and establish a company for the manufacture of dyestuffs.

5. Professional accreditation of academic qualifications is standard practice in the UK. University courses in engineering, medicine, pharmacy, law, accountancy, education and others all share with chemistry the dual requirements of university academic standards and external professional standards. Usually professional accreditation provides exemption from all or part of the qualifying examination for admission to the professional body. Full membership usually entails some additional experience as a practicing member of the profession. For chemists this leads to membership of RSC (MRSC) and a title of "chartered chemist" (CChem).

6. A higher rating of "excellent" was given to 11 departments: 10 of them were "old" universities. There is though no evidence to support suggestions that students will prefer to study in departments with the best teaching assessments.

7. Oxford and Cambridge Universities offer only 4-year courses. For Oxford University this merely constitutes a change in nomenclature from their 4-year BA degree in chemistry to their new M.Chem degree. In effect, by incorporating the 1-year research-qualifying course within the structure of the first degree, the Oxford pattern is the one now adopted by other universities.

8. For the financial year 2003, the allowance will be Pounds 13,000, equivalent to the estimated after-tax earnings of a first-degree graduate in industry.

9. This assumes that the PhD degree will occupy a period of 3 years following 4 years spent on an MChem programme. This constitutes an increase of 1 year in the previously accepted 6-year schedule.

10. These opportunities are more readily available in large research groups and large research schools. The current trend favours larger groups. Advantages conferred by this have to be offset against the reduction in close contact between supervisor and student in such large groups.

11. In the UK there is no provision for applicants for admission as research students to take written entrance examinations. It is assumed that award of a satisfactory first degree together with an interview and a recommendation from a knowledgeable academic provides the necessary basis for admission. Many students choose to remain in the same university for research and this will be reinforced by their experience on MChem courses.

12. Students of foreign languages are required to spend one year of a 4-year degree in a country where the language is used. Such students are properly awarded BA degrees.

13. In the course of writing this article, the author received much helpful advice and enjoyed discussion with many people. He is particularly indebted to Professor P. Hodge and to Dr K MacDonald. The residual omissions, errors and misjudgements are of course entirely the responsibility of the author.

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Appendix

University of Oxford
General Scheme for Lectures in Chemistry

General Chemistry

Second Year
Symmetry (12)
NMR (12)

Third Year
NMR (8)

Other Courses

First Year
Physics and Biological Chemistry
Classical Mechanics (4)
Properties of Gases (4)
Electrostatics (2)
Elementary Optics (4)
Electricity and Magnetism (4)
Origins of the Quantum Theory (4)
Aminoacids, the Peptide Bond and Proteins (4)
Structural Biology (2)
Chemical Basis of Genetics (3)
Metals Ions in Biology (3)
Catalysis in Biology (2)
Introductory Bioenergetics (2)

Biological Chemistry
Introduction to Cellular compounds and their Function (6)
Structure and Properties of Proteins (10)
Reactions of Biomolecules (16)
Membrane Biochemistry (2)
From DNA to Protein (3)

Mathematics for Chemistry
Mathematical Foundations (16)
Integration and Differential Equations (14)
Vector Algebra (8)

Second Year
Chemistry (8)
Synthetic Organic Chemistry II Oxidation and Reduction (4)
High Energy Intermediates in Organic Reactions (4)
Stereoselective Synthesis (8)
Biosynthesis of Natural Products (6)

Third Year
Free Radical Chemistry (6)
Catalysis in Organic Chemistry (4)
Stereoselective Synthesis (8)
Bio-organic Chemistry of Antibiotics (6)
Molecular Organic Materials and Polymers (4)
Peptide Chemistry (4)

Physical Chemistry

First Year
An Introduction to Physical Chemistry (7)
An Introduction to Chemical Thermodynamics (9)
Quantum Theory of Atoms and Molecules (10)
An Introduction to Reaction Kinetics (8)
The Chemistry of Solutions (8)

Second Year
Principles of Quantum Mechanics (8)
Kinetics and Mechanism (4)
Molecular Energy Levels (4)
Molecular Interactions I (8)
Statistical Thermodynamics (8)
Molecular Spectroscopy (6)
Surface Chemistry (6)
Valence and Electronic Spectroscopy (8)
Atomic Spectroscopy (8)
Chemical Reaction Rates (8)

Third Year
Applications of Statistical Mechanics (8)
Modern Liquid Kinetics (8)
Interfacial Kinetics (4)
Photochemistry (6)
Atmospheric Chemistry (6)
Molecular Interactions II (8)

Dynamics of Molecular Collisions (4)
Revision Classes (12)

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Inorganic Chemistry

First Year
Periodicity and Inorganic reactions (4)
Atomic Structure (4)
Ionic Model and Pre-transition Metal Chemistry (6)
Structure of Simple Inorganic Solids (4)
Inorganic Reactions in Solutions (6)
Introduction to Molecular Orbitals (4)
Introduction to Non-metal Chemistry (8)
Review of Inorganic Chemistry (4)
Non-Metal Chemistry (6)

Second Year
Transition Metal Chemistry (12)
Diffraction (4)
Bonding in Molecules (13)
Post Transition Metal Chemistry (4)
Chemistry of Lanthanides and Actinides (4)
Co-ordination Chemistry (6)
Inorganic Reaction Mechanisms (3)
Bioinorganic Chemistry (4)
Solid State Chemistry (8)
Inorganic Applications of Spectroscopy and Magnetism (6)
Organometallic Chemistry I (6)

Third Year
Solid State Chemistry (12)
Organometallic Chemistry (12)
Bio-inorganic and Co-ordination Chemistry (12)
Physical Methods in Inorganic Chemistry (16)
Review of Periodic Table (8)
Review of topics in inorganic Chemistry (6)

Organic Chemistry

First Year
An Introduction to the Principles of Organic Chemistry (16)
Core Carbonyl Chemistry (8)
Chemistry of Other Functional Groups (8)
An Introduction to Organic Synthesis (8)

Second Year
Organic Spectroscopy (4)
Organic Reaction Mechanisms (12)
Aromatic and Heterocyclic Chemistry (12)
Chemistry of Organic ring Systems (12)
Synthetic Organic Chemistry I Organo-B, -Si, -P, and –S
Transition Metals in Organic Synthesis (4)
Pericyclic Reactions (6)
Problem Classes (16)
Revision Course (8)

Supplementary Subjects
Aromatic and Heterocyclic Pharmaceutical Chemistry (32)
Quantum Chemistry (32)
History and Philosophy of Science (16)

Notes for Appendix

1. The School of Chemistry at Oxford claims to be the largest in the western world. It has an academic staff of some 70 senior members and admits 180 students each year to a 4-year course leading to the degree of MChem. There is strong competition for admission and the students will be amongst the most able chemistry students in the UK.

2. The teaching academic year at Oxford is divided into 3 terms each lasting 8 weeks. Attendance at lectures is not compulsory though many students will attend most lectures. The main lecture scheme corresponds to about 8 lectures per week.

3. For their degree course, students are not required to study any subjects other than chemistry. They may well be encouraged by their College tutors to attend the other courses in biological chemistry and mathematics as subjects immediately relevant to the degree course: many of the listed courses in these subjects are taught by academic staff in the School of Chemistry. Quite often students will choose to attend lecture courses in other subjects to satisfy personal interests. Introductory courses in aspects of physics and biology are provided to assist students preparing for the first year preliminary examination and satisfy personal interest.

4. The comparatively large number of short lecture courses (numbers in brackets) reflects the pressures to include a wide range of topics within a chemistry degree scheme. It also derives from the large number of academic staff. On average, each will teach courses amounting to 10 hours over the academic year (with a range of 4 _ 24 hours). A bigger demand on teaching time is provided by the Oxford tutorial system. This will require some 8- 10 contact teaching hours each week for all senior academic staff.

5. Tutorials. All students will attend a tutorial each week with a senior member of the academic staff (tutor). This is compulsory. Students will be required to write an essay dealing with a topic set each week by the tutor and to spend

an hour in the tutorial discussing what has been written. Writing the essay will involve much library work, often with journals and relevant papers. (Hence an Oxford student is said to be "greading for a degree in a subject" rather than simply "studying a subject".)

6. Practical laboratory work is expected to occupy students about 6 _ 9 hours per week. For each 4-week period, students are assigned to one of the laboratories (inorganic, organic, physical chemistry). On four days in the week there is open access for them to the designated laboratory from 1100 _ 1700 hours.

7. Final written examinations are held at the end of the 3rd year. The 4th year is devoted to a research topic and is reported in a dissertation with an oral examination.