Annex 1

Tuning subject area findings: *Chemistry*

1. Introduction to the subject area

Chemistry is one of the basic scientific disciplines, along with physics and biology. It is thus a subject which is understood in the same way in all European countries, and indeed throughout the world. Until recently there would have been general agreement as to the way that chemical education at universities should be organised. Physics and mathematics are subjects which the chemist needs to study in the first year of chemistry education, since some aspects of these form a vital basis for understanding chemistry. Normally the physics and mathematics departments provide the necessary teaching, but it is sometimes found advantageous that chemists themselves teach these two subjects to the necessary level.
The relationship between chemistry and biology is more complex. Biology has traditionally been to a large extent a science of description and classification, but modern biology has moved away from this picture, and indeed biology education at universities is developing in many important directions.
A chemist will often say that "modern biology is chemistry" because so much of modern biology is studied and described at the molecular level. Thus the biologist needs to know much more chemistry than before, and from the point of view of the chemist he or she needs to know much more about biology.
This has been reflected in the growth of biochemistry programmes, which seek to link chemistry and biology. However, biochemistry is not treated in the same way across Europe: it may or may not be integrated with chemistry as far as departmental structures are concerned. Thus there are no uniform platforms for discussion between chemists and biochemists in European universities.
Perhaps as a result of this, there is an emerging trend for chemistry departments to offer new degree courses referred to as "chemical biology". These build on a considerable chemical basis, but include various elements of biology. However, even where such courses do not exist it is becoming apparent that any chemist needs to have certain competences in biology, and to deal with this an additional sub-discipline is being defined. The traditional basic sub-disciplines of chemistry are organic, inorganic and physical chemistry (analytical chemistry is considered by many as a separate sub-discipline, but there is no consensus: teaching of analytical chemistry is often subsumed under inorganic chemistry). The new sub-discipline is referred to as "biological chemistry", and the chemistry group in Tuning considers that teaching in this area is vital for a modern chemistry first cycle degree course, as competences in this area are an absolute must for the chemistry graduate of today.

2. Degree profiles and Occupations

Typical degrees offered in the subject area

- First cycle BSc in Chemistry (see Eurobachelor for planned structures: www.eurobachelor.net)
- Second cycle MSc in Chemistry(Masters degrees may be purely by research or, more typically, by a mixture of course work and a substantial thesis component, usually involving one of the sub-disciplines listed in the Eurobachelor proposal.)
- Third cycle PhD in Chemistry (Doctorate by research, usually requiring examination and defence of a substantial and original piece of research described in a comprehensive thesis)

Typical occupations of the graduates in the subject area (map of professions)

- First cycle: apart from the UK and Ireland, no valid information on first cycle graduate employment is available, because there are virtually no graduates so far.
- Second cycle: here there is not even information from the UK and Ireland, as Master programmes there exist almost only as professional one-year Masters run for people working in chemical/pharmaceutical/life science areas.
- Third cycle: here a majority will probably be employed in chemical/pharmaceutical/life science companies. Various other types of non-chemical employment are however known, particularly in those countries which do not have a manufacturing base in these areas.

Role of chemistry in other degree programmes
Chemistry teaching is important in the following first cycle degree programmes: biochemistry, chemical biology, chemical engineering, physics, mechanical/electrical engineering.

3. Learning outcomes & competences - level cycle descriptors

The "Dublin descriptors" have been adapted so that they can be applied directly to chemistry degrees. The result is the "Budapest chemistry descriptors", which are given below for the first and second cycle.

First cycle degrees in chemistry[1] are awarded to students who have shown themselves by appropriate assessment to:

- have a good grounding in the core areas of chemistry: inorganic, organic, physical, biological and analytical chemistry; and in addition the necessary background in mathematics and physics;
- have basic knowledge in several other more specialised areas of chemistry[2]
- have built up practical skills in chemistry during laboratory courses, at least in inorganic, organic and physical chemistry, in which they have worked individually or in groups as appropriate to the area;
- have developed generic skills in the context of chemistry which are applicable in many other contexts;
- have attained a standard of knowledge and competence which will give them access to second cycle course units or degree programmes.

Such graduates will:

- have the ability to gather and interpret relevant scientific data and make judgements that include reflection on relevant scientific and ethical issues;
- have the ability to communicate information, ideas, problems and solutions to informed audiences;
- have competences to fit them for entry-level graduate employment in the general workplace, including the chemical industry;
- have developed those learning skills that are necessary for them to undertake further study with a sufficient degree of autonomy.

Second cycle degrees in chemistry are awarded to students who have shown themselves by appropriate assessment to:

- have knowledge and understanding that is founded upon and extends that of the Bachelor's level in chemistry, and that provides a basis for originality in developing and applying ideas within a research context;
- have competences to fit them for employment as professional chemists in chemical and related industries;
- have attained a standard of knowledge and competence which will give them access to third cycle course units or degree programmes.

Such graduates will:

- have the ability to apply their knowledge and understanding, and problem solving abilities, in new or unfamiliar environments within broader (or multidisciplinary) contexts related to chemical sciences;
- have the ability to integrate knowledge and handle complexity, and formulate judgements with incomplete or limited information, but that include reflecting on ethical responsibilities linked to the application of their knowledge and judgements;
- have the ability to communicate their conclusions, and the knowledge and rationale underpinning these, to specialist and non-specialist audiences clearly and unambiguously;
- have developed those learning skills that will allow them to continue to study in a manner that may be largely self-directed or autonomous, and take responsibility for their own professional development.

[1] A Eurobachelor qualification
[2] Such as computational chemistry, materials chemistry, macromolecular chemistry, radiochemistry

The chemistry subject area group has devised the Eurobachelor framework for a first cycle degree. This framework refers directly to the Tuning list of generic competences and defines subject-based competences.
The generic competences to be developed during the first cycle (not in order of importance) are:

- capacity for applying knowledge in practice
- planning and time management
- oral and written communication in the native language
- knowledge of a second major European language
- capacity for analysis and synthesis (in a general, not a chemical sense)
- capacity to learn
- information management skills (ability to retrieve and analyse information from different sources)
- capacity to adapt to new situations
- problem-solving
- decision-making
- teamwork
- ability to work autonomously
- ethical commitment

In our discussion of subject-specific competences, which in the Eurobachelor framework we refer to as abilities and skills, we identified the following as relevant to the first cycle:

1. Chemistry-related cognitive abilities and skills

1.1 Ability to demonstrate knowledge and understanding of essential facts, concepts, principles and theories relating to the subject areas identified above.
1.2 Ability to apply such knowledge and understanding to the solution of qualitative and quantitative problems of a familiar nature.
1.3 Skills in the evaluation, interpretation and synthesis of chemical information and data.
1.4 Ability to recognise and implement good measurement science and practice.
1.5 Skills in presenting scientific material and arguments in writing and orally, to an informed audience.
1.6 Computational and data-processing skills, relating to chemical information and data.

2. Chemistry-related practical skills

2.1 Skills in the safe handling of chemical materials, taking into account their physical and chemical properties, including any specific hazards associated with their use.
2.2 Skills required for the conduct of standard laboratory procedures involved and use of instrumentation in synthetic and analytical work, in relation to both organic and inorganic systems.
2.3 Skills in the monitoring, by observation and measurement, of chemical properties, events or changes, and the systematic and reliable recording and documentation thereof.
2.4 Ability to interpret data derived from laboratory observations and measurements in terms of their significance and relate them to appropriate theory.

In Phase III of Tuning the chemistry group intends to continue its work to produce subject-based cycle descriptors. It appeared to us that the state of the discussion in our subject area across the Bologna area was not sufficiently advanced to allow us to do this in Phase II, particularly with respect to the third cycle, the Dublin descriptors for which were only formulated (with the help of the chemistry subject area coordinator) in March 2004.

Consultation process with stakeholders

The chemistry group in Tuning is comprised of members of the European Chemistry Thematic Network (ECTN), which has been running successfully since 1996. This network is financed by the EU Commission. The network comprises mainly academic institutions. It is difficult to involve people from industry as the employer has to provide the time to allow its employees to participate. However, a

number of national chemical societies are members of ECTN, and these societies have a large membership from the industrial chemistry community. The ECTN is trying to get more industrial involvement by getting in contact with industrial organisations, such as the European Chemical Industry Council (CEFIC). However, the distance from bodies such as CEFIC from the industrial floor is great. Thus so far we have not found the correct mechanisms on a European basis for involving chemical industry in our deliberations.
The situation at national level is however different. Thus for example in November 2004 a one-day meeting involving academics and people from industry was held in Germany. Naturally one important topic was the employment potential for graduates from the various cycles, while another was the description for industry representatives of how the Bologna reforms will be carried out in chemistry in Germany. Other such meetings are taking place in other countries.
Another potential opportunity for dialogue, this time between academics and students, was the Bologna Seminar "Chemistry Studies in the European Higher Education Area" held in Dresden, Germany in June 2004. There were almost 200 participants from 25 countries, but despite the efforts of the organizers to involve students, their participation was unfortunately close to zero. One reason for this is that, although there is a European students union, ESIB, there is no corresponding organization for chemistry students.

4. Workload and ECTS

Workload of the typical degree programmes expressed in ECTS credits:

- First cycle 180
- Second cycle 120
- Third cycle is *not* expressed in ECTS credits (average 3-4 years)

Trends and differences within the European higher education area in this subject area.

Chemistry is the only subject area to have produced a European framework for the first cycle (the Chemistry Eurobachelor). A Eurobachelor Label is available to interested institutions, and the introduction of the Label is presently supported by the EU Commission under the Socrates Programme.
Chemistry is also the only subject area to have had its own Bologna Seminar, "Chemistry Studies in the European Higher Education Area", held in June at the TU Dresden (Germany). The conclusions and recommendations of the seminar, which cover all three cycles, can be found on the official Bergen 2005 website (http://www.bologna-bergen2005.no/) under "Bologna Seminars".
The chemical industry is still one of the most important in Europe, with about 3 million employees. Many of these are chemistry graduates, and the industry is starting to get to grips with the new degrees which are being introduced in Europe.
Traditionally, chemistry has been divided into three major sub-disciplines: organic, inorganic and physical. In some institutions a fourth, analytical chemistry, is present as a separate sub-discipline, but is often subsumed under inorganic chemistry. However, chemistry is moving towards biology, so that some countries are introducing new programmes in "chemical biology" (there is also a separate, but related, discipline of biochemistry). It thus seems clear that a new sub-discipline, which we can call biological chemistry, will soon join the three major sub-disciplines.
Chemistry is a well-defined discipline, so that no fundamental differences between degree programmes in European countries are present. One important difference between programmes lies in the amount of time which is devoted to laboratory courses. Laboratories are expensive and require considerable amounts of manpower, so that there is a tendency to cut them back when (as always at universities!) money is scarce.

5. Learning, Teaching and Assessment

5.1 Methods and techniques of instruction and learning, taking into account the differences in cultures both in institutions and countries

In chemistry the differences in culture between countries and between institutions are not that great. Thus methods and techniques for instruction and learning will not differ in principle but more in the extent to which they are used. As has been detailed above, practical courses play a very important role in the education of a chemist. At the same time, these are the most expensive aspect of the training, as they require large amounts of laboratory space, very close supervision, expensive apparatus and chemicals etc. This, together with the fact that in some countries the student intake is very high, means that it is not always possible to provide the student with as much practical training as is really required during the first cycle. The deficits can be made up in the second and third cycles, of course, but here the student numbers are smaller.

5.2 Competence development

There is much discussion as to whether it is possible to separate generic and subject-specific competences. In some subject areas there are proposals to allocate a certain proportion of credits to courses on generic skills given by persons outside the subject area. It is our opinion that in chemistry courses this is not necessary and may even be counter-productive. These two types of competence are often inseparable, as will be shown below.
Our work on genetic competences has shown clearly that the competences referred to above can be and indeed are developed within the normal teaching process (although teachers and students alike have in the past not given though to this). The one key competence where work needs to be done in some departments is teamwork, something which has not been emphasised in course design in the past. The other key competences are developed during normal teaching and thus cannot and should not be divorced from subject area teaching.
In some countries the subject of employability is discussed at some length, since the expression "relevance to the labour market" in the Bologna declaration has been misunderstood in translation. We, as chemists, often have the idea that a BSc in chemistry will not be employable in chemical industry, for example, simply because traditionally there were no bachelors on the market in our particular countries.
It is slowly becoming clear that this situation will change, as industry will certainly modify its attitude when universities offer the "product" bachelor and explain its profile with the ehlp of the Diploma Supplement.
How counter-productive an employability discussion can be in our subject becomes more clear when we consider, say, a history graduate. History graduates are certainly employable, but not in a history industry! They are employable because of the generic skills which they have developed, and in some cases they will be employed in "history-related" positions.
The same is true of the chemistry graduate, as a look at the situation in the UK and Ireland will show. Here the chemistry graduate who takes up a job after graduating with a first degree (and this is the majority) may go into a "chemistry-related" job, but in many cases will not.
Europe needs first cycle degree graduates with a knowledge of chemistry, whatever these graduates do after leaving university!

5.3 Implementation of subject-specific competences: Three Examples

Three aspects of implementation will be covered, i.e. teaching, learning and assessment. In order to gather material on which to base some useful conclusions, a series of questions was posed to members of the chemistry group. Three of these will be considered here:

*How do you help students to achieve this competence in your **teaching methods**?*
What ***learning activities*** do your students engage with in order to develop this competence?
How do you ***assess*** whether, or to what degree, they have achieved this competence?

Ten subject-based competences were selected and members of the group were asked to answer these questions for the competences which were assigned to them. The selected competences had already been assigned by the group as being particularly relevant to the first cycle and thus could be considered as genuine "key competences" in the education of a chemist. Three examples are presented here. In each case corresponding generic competences are given.

5.3.1 Ability to demonstrate knowledge and understanding of essential facts, concepts, principles and theories (Country: France, Grande École). *Corresponding generic skills: capacity for applying knowledge in practice, oral and written communication in the native language, capacity for analysis and synthesis, information management skills, capacity to adapt to new situations, problem-solving, ability to work autonomously.*

How do you help students to achieve this competence in your teaching methods?
Lectures, problem classes, practical classes, and an undergraduate research project. The knowledge and understanding is communicated by means of written answers to questions (problem classes or

examinations) or by an oral presentation of the project work, or presentation of answers to problems in front of the tutorial group.

What learning activities do your students engage with in order to develop this competence?
Lectures, problem classes, practical classes, industrial placements and a research project.

How do you assess whether, or to what degree, they have achieved this competence?
By means of written (and sometimes oral) examinations, continuous assessment of practical work and problem classes. Assessment of the research project includes an oral presentation in which communication skills are assessed as well as scientific understanding.

All assessed work is returned to the student. They are given marks for each examination/assessment, and they are given their class ranking at the end of each semester. Students with difficulties are interviewed by the person responsible for the appropriate year of study, and, if necessary, by the head of studies.

There is a meeting each semester attended by all teachers and by elected representatives of the class. At this meeting, the performance of all students who have not achieved the standard required is discussed so that the reasons for non-achievement can be determined, and communicated to the student if necessary.

5.3.2 Ability to recognise and analyse novel problems and plan strategies for their solution (Norway). ***Corresponding generic competences: capacity for applying knowledge in practice, written communication in the native language, capacity for analysis and synthesis, information management skills, problem-solving, decision-making, ability to work autonomously.***

How do you help students to achieve this competence in your teaching methods?
Students are supervised throughout all laboratory exercises, and skills in observation trained by question and answers sessions, tutorials etc. The significance of the results obtained forms a part of all laboratory reports as does relation to the appropriate theory.

What learning activities do your students engage with in order to develop this competence?
Laboratory work and writing of laboratory reports is the most important method of achieving these skills.

How do you assess whether, or to what degree, they have achieved this competence?
Student laboratory performance is assessed on a continuous basis by staff present in the laboratory, and laboratory reports carefully checked. Examinations in connection to laboratory courses are also of some importance

5.3.3 Planning, design and execution of practical investigations (Spain). ***Corresponding generic skills: capacity for applying knowledge in practice, planning and time management, oral and written communication in the native language, capacity for analysis and synthesis, information management skills, capacity to adapt to new situations, decision-making, ability to work autonomously, ethical commitment.***

How do you help students to achieve this competence in your teaching methods?
Through exercises and practical examples: setting the scene, clarifying issues, and helping students to recognise and become familiar with the scheme for developing a correct strategy.
Homework tasks with selected topics which teams of students could make exercise.
Discuss their work in class in order to optimise their results.

What learning activities do your students engage with in order to develop this competence?
Attend seminars and tutorials. Participate in discussions after different working groups presentations analysing procedures.

How do you assess whether, or to what degree, they have achieved this competence?
Following up on their homework during tutorials.

6. Quality enhancement

Tuning has identified a series of steps in designing new degree programmes:

1. Definition of academic and professional profiles: translation into learning outcomes and generic and subject specific competences
2. Translation into curricula
3. Translation into modules and approaches towards teaching, learning and assessment
4. Programme quality assurance: built in monitoring, evaluation and updating procedures

As far as chemistry is concerned, these cannot be applied in the same manner to first, second and third cycle programmes. The following discussion will be structured according to points 1 to 4 and not according to cycles, however.

6.1 Definition of academic and professional profiles: translation into learning outcomes and generic and subject specific competences

First cycle

Academic and applied Bachelor programmes are available in Europe, but there appears to be only a small number of applied degree courses available or in planning in pure chemistry. Applied chemistry-related degrees are more likely to be in chemical engineering. A recent survey shows that more 180-credit programmes are likely to be offered, though there appears to be a trend towards 240 as one moves East in Europe. Spain, unfortunately, has not made a final decision, though Catalunya has a pilot project for 180-credit degrees.
The question of defining a difference in profile between 180- and 240-credit programmes does not appear to have been addressed at all. There are merely political, not subject-based, reasons for going in one direction or the other.

Second cycle

In chemistry it appears at present that "academic" Masters will become the norm in post-Bologna Europe. The Dresden Bologna Seminar made the following recommendations:

- 120 ECTS credits should be the reference point for Master programmes.
- The Master thesis should carry at least 30 ECTS credits and the research work should be organized over a defined period of time in order not to hamper student mobility.
- At the second-cycle stage institutions will in future have to compete on both a national and international basis for the best students. Thus they will need to design attractive study programmes which reflect their individual structures.
- The definition of a "Euromaster profile" analogous to the Eurobachelor will not be possible, because of the greater degree of specialisation of the former. However, the joint degree framework envisaged by the ERASMUS MUNDUS programme can act as a model for the development of genuinely "European" qualifications in chemistry.
- Access criteria for second-cycle programmes must be flexible and carefully-devised in order to make the programmes attractive. The right of access envisaged by the Lisbon Recognition Convention must be respected. No quota systems should be imposed, as these affect the rights of the individual as well as of the institution.
- Flexibility based on the bachelor diploma supplement should be introduced to handle specific situations (change of orientation, non-European students, excellent students)
- High-quality students must be afforded the possibility of transferring to a doctoral programme without formal completion of the Master degree, as stated in the recommendations of the Helsinki "Bologna series" Master conference.
- It is broadly accepted that a second cycle qualification will take a total of around five years of study to obtain, although the precise duration will depend on the learning outcomes to be achieved. Where the study pattern is, for example, 4+1 as opposed to 3+2 years, admission to a one-year second cycle course could at present involve a requirement for extra study or experience from a 3-year first cycle graduate, e.g. industrial experience.
- Master courses should be taught in English on request wherever possible.

The UK has second-cycle one-year Masters which can be referred to as more "professional" in nature, but there does not yet seem to be a tendency in continental Europe to go down that road. Instead, it appears likely that master programmes will carry 90-120 credits according to the Helsinki recommendations. The question of organising the transition of suitably qualified candidates from master to PhD programmes without formal award of a master qualification is still under discussion on a national basis, but mechanisms will become established in the next few years.

Third cycle

In chemistry, the third cycle has a purely academic profile. Traditionally, it consisted only of research (generally basic but also applied) supervised by a single academic supervisor and leading after an undefined period to the award of a PhD (or corresponding national qualification) on the basis of the thesis submitted and an examination carried out according to national or local regulations.
However, the picture across Europe is presently not uniform. More and more there is movement away from the "research only" PhD to structured PhD programmes, and quality enhancement will have as its major task the development of such programmes and their adaptation to the changing needs of our science.
According to an ECTN survey carried out in 2002, the "average" PhD in Europe will have:

- taken 3-4 years for his/her thesis
- done some work as a teaching assistant
- been supervised by one supervisor
- written intermediate reports before writing the thesis
- been the author of at least one publication in an internationally refereed journal
- written his/her thesis in English or the national language
- passed the examination without grading
- done some coursework (up to 60 ECTS credits)
- taken a public oral exam with at least one external examiner
- done his/her PhD in the home country

The recommendations of the Dresden Bologna Seminar for the third cycle were as follows:

- Structured degree programmes which include coursework (in the widest sense of the term) should become a common feature of European PhD studies; however, research must still be the major element of such programmes. Part-time PhD studies should remain possible in institutions where it has been a normal feature.
- The average European PhD should spend 3 to 4 years on his or her studies. The research element of the PhD study programme should not be awarded ECTS credits.
- ECTS credits should be used to quantify the coursework component. These credits can however be ungraded, as the correct use of the (relative) ECTS grading scale will not be possible. A wide range of ECTS credits (anywhere between 20 and 60) can be envisaged. Use of the national grading scale is of course possible.
- Apart from research and coursework, further important elements of the PhD programme are teaching (as teaching assistants) and the training of key generic skills, such as those listed in the Appendix of the Chemistry Eurobachelor document.
- Institutions should issue transcripts containing information on all the coursework carried out, and on work done as a teaching assistant. Such transcripts will probably not use the standard European Diploma Supplement format.
- Institutions are encouraged to develop "Graduate School" structures at departmental, interdepartmental or regional level in order to increase their national and international visibility, to increase their research potential and to foster cooperation both between
- staff and between students.
- National structures for setting up research networks should be extended in order to internationalise such networks. PhD students should spend part of their research time at other institutions, preferably in foreign countries.

6.2 Translation into curricula

First cycle

The design of curricula is the province of the academic staff. It is important to try not to restrict their freedom unneccesarily, while at the same time defining standards.

The chemistry Eurobachelor does not attempt to define curricula in any detail. It suggests the following features:

a) a "core" of at least 90 credits of compulsory modules/courses, taken from the following areas:
   - organic chemistry
   - inorganic chemistry
   - physical chemistry
   - analytical chemistry
   - biological chemistry
   - physics
   - mathematics
b) semi-optional courses covering at least three further sub-disciplines (at least 5 credits each)
c) optional courses
d) a Bachelor thesis with 15 credits.

Within these limits the institution is free to structure its degree.

Second cycle

The major element of Master programmes will be the research component, which will probably carry between 30 and 60 credits (30 may become the norm, but this is not yet clear).
There will be a certain compulsory element in Master programmes, but these will generally be very flexible as there will be a connection between coursework and the direction of the research area chosen. The Master programme in chemistry will not be simply a continuation of the Bachelor programme.
While it appears advisable to define a framework for a Bachelor programme (the Eurobachelor), no such framework is necessary for a Master programme.

Third cycle

There will be no defined curricula. Instead, the ideal situation is that each PhD student is counselled on the courses he/she should take as part of the defined amount of coursework.

6.3 Translation into modules and approaches towards teaching, learning and assessment

First cycle

The translation into modules is left entirely to the department or faculty concerned. However, as far as teaching, learning and assessment is concerned, the Eurobachelor framework does make some important statements. Masters degrees may be purely by research or, more typically, by a mixture of course work and a substantial thesis component, usually involving one of the sub-disciplines listed above. A significant number of such courses have strong connection with industry.

Second cycle

The same applies as for the first cycle, as there is no fundamental change on going from one to the other. Naturally the competences will change.

Third cycle

The important aspect here is assessment. Two points are involved, both of which are concerned with the thesis. Firstly, the reviewing and (if required) grading of the thesis needs to be put on an open footing, with the involvement of external examiners. Secondly the extremely disparate procedures for the final examinations of PhD students need to undergo a certain amount of harmonisation.

6.4 Programme quality assurance: built in monitoring, evaluation and updating procedures

First cycle

Monitoring will consist mainly of following the progress of the students (in terms of assessment results) through the individual modules/course units. At the same time a database on where graduates go after

graduation will be necessary. Monitoring will naturally include feedback from the students (evaluation) on the individual modules/course units; this will include feedback on actual workload. Correlations between workload and assessment results can be derived. Updating must be carried out continually. *Second cycle* The same applies as for the first cycle. *Third cycle* Monitoring will be a difficult process. Firstly institutions need to build up a database on where their graduates go after leaving the university. One element here can be the establishment of a functioning alumni programme. With the help of the database it will then be possible to carry out evaluation of the success of the graduates in their chosen professions.