Learning, Teaching and Assessment

Introduction

The fundamental difference between the first and second cycle qualifications in chemistry is that the second is to a large extent research-based, at least 25% on average of the credits probably being allocated to the research forming the basis of the Master Thesis. In addition, there will often be much more flexibility in the selection of the courses taken, so that no general statements as to the importance of particular learning outcomes can be made.

Teaching: types of courses which are mostly used in chemistry degree programmes

Lectures

As in any degree course, formal lectures play an important role in chemistry programmes, taking up the lion's share of the contact hours. This will be true for both first and second cycle programmes.

Practical Courses

Chemistry is however an "unusual" subject in that the first cycle student not only has to learn, comprehend and apply factual material but also spends a large proportion of his/her studies on practical courses with "hands-on" experiments, i.e. there are important elements of "handicraft" involved.

Practical courses must continue to play an important role in first cycle university chemical education in spite of financial constraints imposed by the situation of individual institutions. They may be organised as separate modules or as integrated modules. Both alternatives have advantages and disadvantages: if they are organised as separate modules, the practical content of the degree course will be more transparent. Integrated modules offer better possibilities for synchronising theory and practice.

In the second cycle there will generally be less formal practical education, but a shift towards practical work related to the planned thesis. Naturally there are areas of chemistry where the research is not of a practical nature (computational chemistry comes immediately to mind), but for most chemists work "at the bench" will continue up to the PhD stage.

Problem-solving Classes

Two key competences involve the "ability to apply chemistry knowledge and understanding to the solution of qualitative and quantitative problems of a) a familiar and b) an unfamiliar nature". These key competences must be heavily involved in teaching. Although institutions will deal with this in different ways, such types of instruction will be referred to here as "problem-solving classes". They may well involve splitting up the cohort into smaller groups.

Problems will be of a familiar nature in cycle one, but cycle two should involve more use of unfamiliar problems.

Tutorials

This term refers to work with small groups, and may be organised in various ways.

Seminars

This term is often used somewhat loosely, and may sometimes be synonymous with problem-solving classes. A seminar may however also well involve a type of course in which the student is more actively involved, for example in oral presentations.

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.

The following methods of learning are foremost in chemistry:

- Participation in lectures: listening and taking notes during lectures
- Practising technical skills: regularly exercising practical abilities
- Reading books and papers: ability to search for a faster and more effective way of accessing information for academic purposes from books and papers
- Surveying literature: recording (and commenting) the set of works (books, articles, web-pages, etc.) on a particular subject
- Writing papers: drawing up or formulating essays, articles, etc.; the papers can be of increasing difficulty in terms of length, size and complexity of the subject
- Co-producing papers: drawing up or formulating a paper in a co-operative way
- Presenting papers: writing/composing/drafting speeches and reading or delivering them (often using Powerpoint)
- Project-based laboratory work: can be very productive in the second cycle in terms of competences.

Methods of assessment, taking into account the differences in cultures both in institutions and countries

The assessment of student performance is normally based on a combination of the following:

- Written examinations
- Oral examinations
- Laboratory reports
- Problem-solving exercises
- Oral presentations
- The Bachelor or Master Thesis (or in pre-Bologna programmes the theses involved in them).

Additional factors which may be taken into account when assessing student performance may be derived from:

- Literature surveys and evaluations
- Collaborative work
- Preparation and displays of 'posters' reporting thesis work

Some comments on each:

Written examinations: formal written test or evaluation at the end of a course or a course unit; can have an open- or a closed-book form. These are the cornerstone of assessment in many countries. They are likely to vary in length anywhere between two and six hours. While they may be set at the end of each course, intermediate examinations during courses are possible.

Oral examinations: normally formal oral test or evaluation at the end of a course or a course unit. Other countries have always relied on oral examinations to grade students for their final marks, while they may make use of intermediate written examinations to help the student check his/her progress.

Written versus Oral
Any discussion as to which type of examination is best is always in danger of turning to a semi-religious debate, as there will never be agreement on which is really better.

**Comprehensive examination:** exhaustive evaluation of learning outcomes achieved in several course units and over last and previous years. *Permissible under ECTS, but must if used carry credits which take into account required private study time!*

**Laboratory reports:** written accounts on the practical experience gained when performing an experiment (description, observation, data taking, analysis, results and conclusions)
Laboratory reports are a vital part of education in chemistry, but will not always be marked in such a way that the results find their way into final grades.

**Problem-solving exercises**
These are normally involved in continuous assessment and performance may well be integrated in final grading of courses.

**The Bachelor, Master or PhD Thesis:** a (long) treatment/report based on individual work and usually formally presented. Often presented orally, the importance of the quality of the presentation and the demands made on it increasing steadily from the first to the third cycle.
In some countries theses will be graded, in others only a pass/fail system is used.

**Thesis/dissertation defence/viva (viva voce):** formal presentation containing arguments to show the quality of the contents.

**Literature surveys and evaluations**
These will often be required, but not normally assessed other than in a pas/fail manner.

**(Oral) presentation:** a verbal presentation to a lecturer and to other students by an individual student.
Use of this teaching and assessment tool is highly encouraged!

**Internship report:** a written account on the experiences gained during an internship.

**Paper/essay:** a (short or long) piece of (original) writing on one subject and for specialists.

**Collaborative work**
Traditional chemistry degree programmes tend in many countries not to involve collaborative work except at the level of laboratory coursework. This situation is now changing, as teamwork is accepted to be a vital competence for chemists, which must be stressed when courses are under construction.

**Preparation and displays of posters reporting thesis work**
This is common in some countries, unknown in others. Posters will tend not to be assessed quantitatively.

**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 generic 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 help 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, not only as secondary school teachers, 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!

**Implementation of subject-specific competences**

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. In each case corresponding generic competences are given.

1. **Ability to apply chemistry knowledge and understanding to the solution of qualitative and quantitative problems of a familiar nature (Country: Belgium).** **Corresponding generic competence: problem-solving.**

*How do you help students to achieve this competence in your teaching methods?*

Exercise classes are regularly organized under the supervision of tutors or teaching assistants. Typical exercises (in particular from previous exams) should have ideally first been prepared by the students at home.

Most afternoons are dedicated to laboratory work in all fields of chemistry. The practical work is designed to both illustrate basic principles taught during the lectures and help the students learn the basic experimental strategies.

Interactions with the programming courses are encouraged so that this programming competence can be applied in the home-works.

Tutors are available to help students who have difficulties.

*What learning activities do your students engage with in order to develop this competence?*

They reach a deeper understanding of the basic theoretical principles. The students become progressively more independent and they learn to practice the experimental work of a chemist.

*How do you assess whether, or to what degree, they have achieved this competence?*

Written tests are organized on a regular basis (formative evaluation). The laboratory work is evaluated both from the point of view of the quality of the experimental work and from the point of view of the level of understanding. Laboratory reports are required.
2. Ability to Conduct Risk Assessments (Country: Germany). **Corresponding generic competences:** oral communication in the native language, capacity for analysis and synthesis, information management skills.

**How do you help students to achieve this competence in your teaching methods?**
Chemistry students have to go through a number of practical laboratory courses in which they have to do set experiments within a given time framework. At the beginning of the course the students are given written instructions as to how to prepare a risk assessment. Before doing experiments in the practical laboratory, the students have a discussion with a teaching assistant, who will check whether the student has done the risk assessment correctly.

**What learning activities do your students engage with in order to develop this competence?**
Using as an example an organic laboratory: the student is told which experiment is to be done. He/she then has to inform himself/herself about it and plan how he/she will do it. This planning includes deciding how much of each chemical will be required. He/she is required to inform himself/herself about the hazards involved in working with each compound involved and also how to dispose of residues from the experiment (which might themselves be to some extent hazardous). A written risk assessment must be prepared.

**How do you assess whether, or to what degree, they have achieved this competence?**
At the end of the course we have a detailed record of their progress. Their work, which includes the risk assessments required, is then assessed by the teaching assistants.

3. 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.

4. Ability to interpret data (Scotland). **Corresponding generic competences:** capacity for applying knowledge in practice, written communication in the native language, problem-solving.

**How do you help students to achieve this competence in your teaching methods?**
Instruction sheets for the laboratory work generally tell the students what graphs to draw, what tables to prepare, but the laboratory reports are expected to include a “discussion” section which is part of
the assessment. At the lower levels (years one and two) there are also “questions” for them to answer, designed to get them to think about their observations in the context of theory! In the second cycle, this skill is part of that which a supervisor is expected to encourage.

What learning activities do your students engage with in order to develop this competence?
The second year class “Handling Chemical Data” is designed to give the students basic tools in the areas of statistics, errors, quantitative methods, so that they can better assess the strengths and the limitations of their practical work. After that - laboratory work, placement and final year project.

How do you assess whether, or to what degree, they have achieved this competence?
Contributions come from the continuous assessment of the taught class, from marked laboratory reports, from the assessed placement and from project dissertations. The written examinations, particularly in year five, include some questions which ask for data to be interpreted, at the instigation of several of our external examiners.

5. 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

6. 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.

7. Information Retrieval Skills (Greece). Corresponding generic skills: knowledge of a second major European language, information management skills, ability to work autonomously.

How do you help students to achieve this competence in your teaching methods?
Special practical courses take place in the library/on the computer. Seminars demonstrate difficult real case studies.
What learning activities do your students engage with in order to develop this competence?
Students participate in seminars as above. Homework case studies are prepared in all branches of chemistry

How do you assess whether, or to what degree, they have achieved this competence?
Homework is assessed as to the competence to have all information and no more than that. Examinations focusing on case studies take place.

8. Skills in the Monitoring, by Observation and Measurement, of Chemical Properties, Events or Changes, and the Systematic and Reliable Recording and Documentation Thereof. (The Netherlands). Corresponding generic skills: planning and time management, written communication in the native language, teamwork, ethical commitment.

How do you help students to achieve this competence in your teaching methods?
In the lab courses small teams are formed and the supervisors demonstrate and verify the monitoring, by observation and measurement, of chemical properties, events or changes. This is part of the instruction. They learn to make reports. During the study, with the increase of the experience of the student, also the responsibility of the procedure and the collection of data increases. Later in the study in projects and in the Bachelor Thesis the experiments are more and more on an individual basis. There is however still supervision of the whole process.

What learning activities do your students engage with in order to develop this competence?
Learning by doing in the laboratory (see previous answer).

How do you assess whether, or to what degree, they have achieved this competence?
These skills improve with time and can easily be assessed by the accompanying tutors and supervisors.

9. Skills in the safe handling of chemical materials, taking into account their physical and chemical properties including any specific hazards associated with their use (Portugal). Corresponding generic skills: capacity to learn, capacity to adapt to new situations, decision-making, ethical commitment.

How do you help students to achieve this competence in your teaching methods?
The importance of following safety regulations and procedures is permanently referred in theoretical and particularly in laboratorial classes. When they start having laboratory classes they are informed about the existence of a “book” with the safety regulations and procedures of our department and with key information about chemicals hazards, EC pictograms, EC risk and safety phrases etc.

What learning activities do your students engage with in order to develop this competence?
Students can only be in the lab if they follow basic rules such as wearing protective wearing and glasses, no eating, no drinking, etc.) Basic procedures related to fire extinguishing, what to do in case of body contact with general chemicals (acids, bases, oxidants etc.) are clearly explained in the first classes. Real situations/accidents from the department are used as examples. The preparation of any laboratory work includes a detailed analysis of the risks related to the chemicals involved in the experiment the student will carry out. To do this the student is encouraged/obliged to analyze and report the MSDS safety data. The safety preparation should be always discussed with the professor before starting. Periodically accident simulations are carried out to test the response of all persons in the building.

How do you assess whether, or to what degree, they have achieved this competence?
The adequate analysis of the safety aspects is an important point in the analysis of practical work reports. The behavior of the students in the lab/building during laboratory classes and during accident simulations should be followed by the professors.

10. 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 (Belgium). 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, teamwork, ability to work autonomously, ethical commitment.

**How do you help students to achieve this competence in your teaching methods?**
Laboratory work represents an important part of the chemists’ curriculum
The basic “handicraft” competences are taught during the first two years of the first degree.
The third year of the first degree and the first year of the second degree give the students the opportunity to become more and more independent.
The labs are organized as modules of eight students, to favour team work.
Literature retrieval work is coupled to the synthetic and analytical activities.
The students are given the opportunity to use research instruments (under supervision!).
Stays in industry are practiced at a limited level and should be encouraged.

**What learning activities do your students engage with in order to develop this competence?**
They learn progressively to plan and perform experiments and to use sophisticated instrumentation.
They perform error analysis using statistical tools, interpret spectroscopic data linked with their experimental project, use separation techniques and interact with researchers in the research labs.

**How do you assess whether, or to what degree, they have achieved this competence?**
Practical work is evaluated based on the quality of the work in the laboratory, on a written report and on a short talk.
Theoretical knowledge on the techniques used is evaluated regularly (formative evaluation).