



Implementing Outcomes-Based Education in Chemistry and Chemical Engineering

**European Chemistry and Chemical Engineering
Education Network**
www.ec2e2n.net

Work Package 15

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Learning outcomes (LOs) are simply statements of what a student should know, understand and/or be able to demonstrate after completion of a period of learning.

1. Introduction

University course documentation has traditionally been written in terms of syllabi describing what is to be taught. Unfortunately, as we are now all too well aware, what we teach and what our students actually learn are often quite different, and there is clearly a need to specify what successful students should be expected to know or be able to do *i.e.* the learning outcomes for our courses. The aim of this booklet is to provide help and information to university teachers unfamiliar with an outcomes-based approach to adopt to the new requirements. While it is clearly important that other stakeholders such as students and employers also understand the process they are not the target audience for this document. After reading the booklet it is hoped that academics will understand what is meant by learning outcomes and why they should be used, will be able to formulate and write descriptors in terms of learning outcomes for their courses and programmes and will be capable of validating that learning outcomes have been achieved through appropriate assessment procedures. We have tried to keep our approach as simple as possible but include many contemporary references to provide background and further details on all the key issues.

1.1 What are Learning Outcomes?

According to the ECTS guide (2009), learning outcomes provide verifiable statements of what learners who have obtained a particular qualification, or completed a programme or its components, are expected to know, understand and/or be able to do. Learning outcome statements are typically characterized by the use of active verbs expressing knowledge, comprehension, application, analysis, synthesis and evaluation. This definition serves to emphasize the links that must exist between teaching, learning and assessment. Learning outcomes that are not assessed are merely aspirations. Learning outcomes can be written for an entire learning programme, a course, a unit or even for a single lesson (Nicholson, 2011).

The learning outcomes approach focuses on what the learner has achieved and is able to demonstrate at the end of the learning activity rather than on the intentions of the teacher. This student-centred approach is what makes the difference between the aim, the objective and the learning outcome of a teaching activity (Kennedy *et al.*, 2007).

- The aim is a general statement of what the teacher intends to cover in a block of learning.
- An objective is a specific statement of the teacher's intentions, which covers a specific area of what the teacher intends to cover in a block of learning.

Aims and objectives are therefore expressed from the teacher's point of view and deal with the intended results of teaching and learning. Learning outcomes, however, consider learning from the students' point of view and deal with the achieved results.

The following definition can be considered a good working definition: a learning outcome is a specific statement that indicates what a student should know and be able to do as a result of the learning (Goff, 2010). Such learning outcomes are specific, verifiable, student-centred and performance-based.

1.2 Learning Outcomes and the Bologna Process

The Bologna Declaration, signed in June 1999 by European ministers with responsibility for higher education, set in motion events, which eventually led to the launching of a common European Higher Education Area (EHEA) in March 2010. The overall aims of the Bologna process have been to improve the efficiency and effectiveness of higher education throughout Europe and to promote mobility within the European Community (EC) by prescribing increased transparency and comparability between degree courses. The three overarching principles of the Bologna process have been: the introduction of a three-cycle system (bachelor/master/doctorate), quality assurance at all levels, and consistency of recognition of qualifications and periods of study. In the context of the Bologna process LOs are considered essential building blocks for transparency within higher education systems and qualifications, and as necessary to promote the mobility seen as vital to support a pan European knowledge-based economy. All higher education programmes and significant constituent parts should therefore now be expressed in terms of LOs. To date some forty-seven countries have signed the Bologna Declaration.

1.3 Learning Outcomes and Employability

According to the Bologna declaration, "The degree awarded after the first cycle shall also be relevant to the European labour market as an appropriate level of qualification". Higher Education Institutions (HEIs) are now, therefore, expected not only to educate students in their chosen discipline, but also to help to prepare them for employment and citizenship. While employers sometimes complain that HEIs fail to provide degree programmes that produce graduates with the skills that they require (Begitt and Drasar, 2009), the Higher Education (HE) sector responds that graduates are not being prepared to meet the needs of any particular job or employer but rather should be equipped for a variety of employment opportunities. Most of us, in fact, would surely agree that in general, chemistry and chemical engineering graduates are highly sought after by employers, not only within their subject discipline but also in many unrelated areas (Grice and Gladwin, 2004). Kemp *et al.* (2008) have suggested a lack of dialogue between specific employers and HEIs as a possible reason for this disagreement.

While discipline specific learning remains a major goal for chemistry and chemical engineering graduates, the importance of learning beyond the knowledge of a specific discipline was stressed by Dearing (1997) in a report, published in the UK, which identified a number of skills to be developed by students during their time at HEIs. These skills, variously referred to as generic skills, core skills, common skills, key skills, employability skills, basic skills, essential skills, transferable skills, critical enabling skills and process independent goals are qualities and traits that students need to develop and master in order to succeed in their studies and future careers. The term "soft skills" is also sometimes used, though this term is usually intended to refer only to 'interpersonal' skills such as communication or group work.

Generic skills are skills, other than subject specific or technical skills, which are nonetheless necessary for the successful performance of a range of jobs and tasks.

Such skills cannot be developed overnight but are rather something that an individual develops over time through practise and experience. In the past such skills were often learned on the job, whereas nowadays employers often require evidence that such skills have already been developed before offering a job. Kasa is quoted by Hamzah and Abdullah (2009) as stating that generic skills are: *"Those skills which can be used across large numbers of different occupations. They include what are defined as key skills – communication, problem solving, team working, IT skills, application of number and an ability to improve personal learning and performance. They also include reasoning skills, scheduling work and diagnosing work problems, work process management skills, visualizing output, working backwards for forward planning purposes and sequencing operations"*. Attitudes to work, such as honesty and reliability, are also important to many employers and are often identified under skills shortages.

Chemists tend to identify problem solving, communication, analytical data analysis, critical appraisal, time management and team working as being particularly important (Grice, 2009), while the Chemical Engineering fraternity list; communications, team working, problem solving, numeracy and IT as the five key transferable skills (Grant and Dickson, 2006). Grant and Dickson further suggest that such transferable skills are more likely to be developed when embedded into the curriculum rather than being taught in separate modules/units. The CHEMEPASS project stressed the need to both design curricula, and foster teaching methods that will promote the learning of competences and skills that will be needed in tomorrow's economy (Ramsuroop, 2006). A recent survey of 196 graduates from nine UK universities, which sought to identify areas of the chemistry curriculum, including generic skills that were particularly useful for new graduates, concluded that generic skills are even more important than chemical knowledge skills (Hanson and Overton, 2010). Rising out of the Bologna process the EUROBACHELOR® qualification has been designed to provide a first cycle degree which will be recognized as being of an acceptable standard, by employers and higher educational establishments throughout Europe. Within such a degree it is not merely sufficient to have a good grounding in chemistry, graduates are also expected to have developed generic skills in the context of chemistry that are applicable in many other contexts (ECTNA, 2007).

Required generic skills change rapidly with time. Little more than a decade ago computing and information technology were regarded as subject-specific knowledge to be left to the experts, whereas nowadays familiarity with computers and a wide range of IT skills are considered essential for any graduate. Quantitative research suggests that the importance to industry of certain generic skills is rapidly increasing with demands for influence skills, literacy, and self-planning becoming increasingly prominent, while the demand for others, such as physical skills, has remained unchanged (Clayton *et al.*, 2003).

The Tuning project consulted graduates, employers and academics in seven subject areas, including Chemistry, about the subject-specific and generic skills and competences that graduates should possess. Thirty generic competences grouped in the three categories: instrumental, interpersonal and systemic were considered (Tuning Educational Structures in Europe), and respondents were asked to rate both the importance and the level of achievement by educational programmes in each competence, and also to rank the five most important competences.

Competences considered as the most important included: a capacity for analysis and synthesis, the capacity to learn, the ability to solve problems, the ability to apply knowledge in practice, a capacity to adapt to new situations, concern for quality, information management skills, ability to work autonomously, and teamwork. While at the other end of the scale, understanding of cultures and customs of other countries, appreciation of diversity and multiculturalism, ability to work in an international context, leadership, research skills, project design and management, and knowledge of a second language were considered relatively unimportant. A striking aspect of this survey is the relatively low importance ascribed to "international competences". Given the current trend towards globalization the wisdom of such a view is questionable.

Many course documents list the key skills and write mapping tables to relate these skills to the learning outcomes. The UK Higher Education Academy Physical Sciences Centre in its leaflet "Using your Chemistry degree to get a job" (The Higher Education Academy, 2010) gives advice to graduates on how to identify attributes, which employers seek, from the course content of a degree. For example, suitable evidence for the ability to work with others in a team might be provided by group laboratory projects or work experience. In conclusion, when writing learning outcomes for a course or module, the writer should take into account the transferable skills which are being developed on achievement of the learning outcome, thus aiding the employability of the students. When writing learning outcomes for any course, programme or module, it is therefore important, that the views of employers should be taken into account. The role of learning outcomes and the close relationship between learning outcomes and employability is illustrated in Figure 1 below.

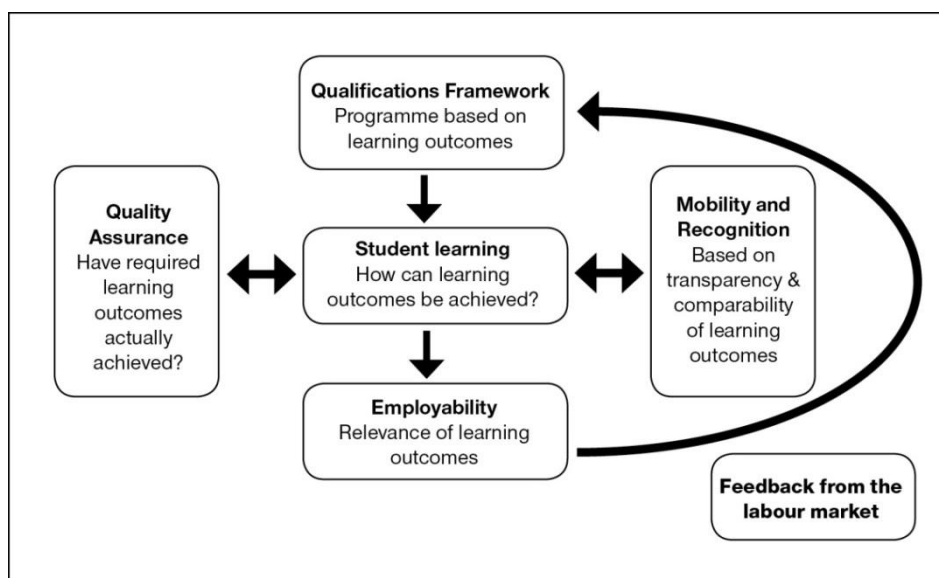


Figure 1: Learning Outcomes in Higher Education and Employability

1.4 Outcome-based Design

In any learning outcomes-based approach the curriculum must be concerned with both content to be learned and the behaviour (skills, abilities, attitudes) to be developed. Therefore any approach to curriculum design, must account for both aspects. This will involve far more than merely writing a wish list of desirable outcomes. The starting point, after considerable thought and discussion, must be a

clear statement of the learning outcomes required following any period of study. Only once this has been done should consideration be given to the delivery of the learning programme in terms of the teaching, learning and assessment strategies that will facilitate the development and assessment of the required outcomes. This is likely to be an iterative process as only when the assessment package has been finalized can the arrangements for teaching be completed.

McMahon (2006) reported that students tend to adopt either a shallow or deep approach to learning in response to their experiences in the classroom and their understanding of what the assessment regime requires, and goes on to suggest therefore, that it ought to be possible to prompt students to adopt deep learning approaches by manipulating teaching and assessment strategies. These ideas are in agreement with those of Biggs (1996) who concluded that it is vital to align learning outcomes, teaching and learning activities and assessment tasks, where the intention is to encourage deep, rather than surface, approaches to learning. Biggs calls this approach, which entails the following steps: a) Defining the learning outcomes, b) Selecting learning and teaching activities that enable the students to develop the outcomes and c) Selecting appropriate assessment activities which allow the student to demonstrate that the outcomes have been achieved to the appropriate level, "Constructive Alignment". The main concepts of constructive alignment are illustrated in Figure 2 below. Course design will be discussed further in section 3.

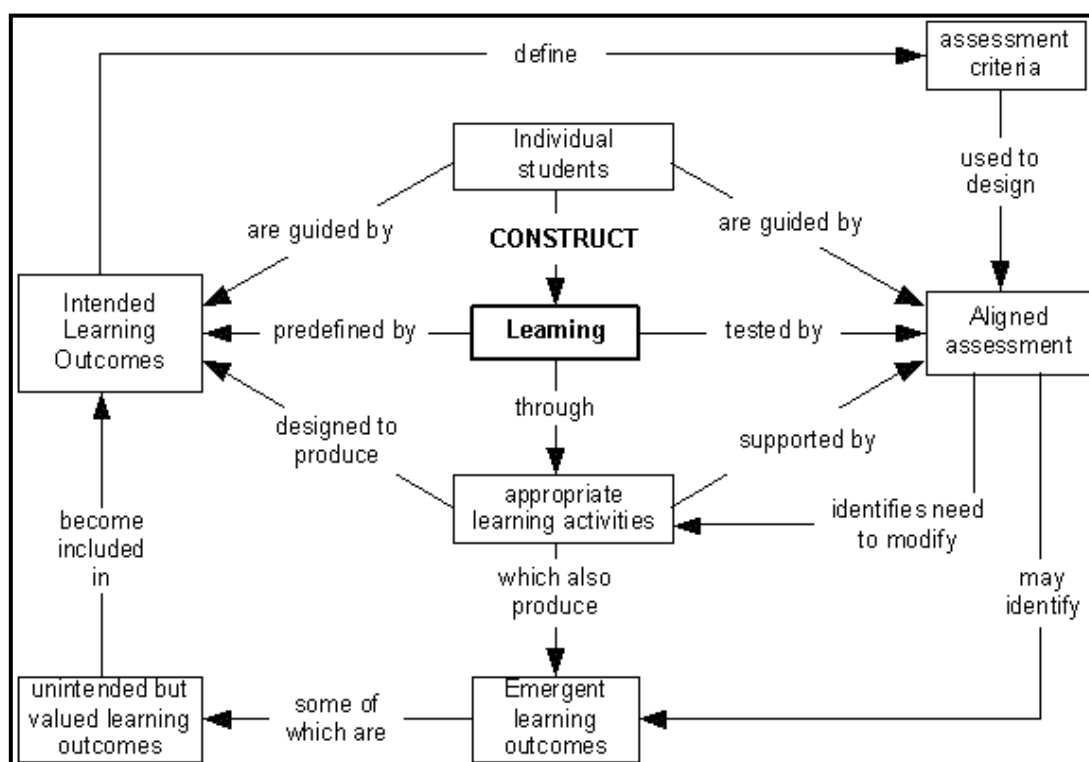


Figure 2: Concept Map Illustrating the main ideas put forward by Biggs on Constructive Alignment, (Houghton, 2004). *Reproduced with permission from the Centre for Engineering and Design Education.*

2 Learning Outcomes

2.1 Writing Learning Outcomes

Quality assurance developments in higher education have encouraged a move to an outcomes-based approach to teaching, learning and assessment. Programme specifications, benchmark statements and the National Qualifications Framework define the student in terms of what they can do at the end of a programme or a particular level of study. This is a change from the more traditional approach where academics tended to define courses in terms of what is taught, rather than what the student can do at the end of the module or programme.

There is much debate in the educational literature about the value of defining learning outcomes to the learning process, and the effects that they may have on student learning. Although many academics have serious misgivings about the benefits of using an outcomes-based approach, as many of us are now required to define our courses in these terms, our aim here is to give some advice on how to do this as painlessly as possible.

Moving to this approach requires academics to think about what they ask their students to **do** during various formative and summative assessment activities. What students can do at the end of a learning opportunity defines the learning outcome. Stated outcomes must be realistically achievable by the students and should not merely constitute a tutor's 'wish list'.

Our aims in teaching a particular module may be to engender 'understanding' or 'appreciation' of a particular topic. Learning outcomes should not use terms such as 'understand' or 'appreciate' as it is not immediately obvious to a student what they have to do in order to demonstrate that they 'understand' or 'appreciate' something. Understanding cannot be directly assessed, only inferred from the outcomes of other activities. Tutors should think about how they ask their students to demonstrate their understanding. They may ask students, during an examination, to **describe** a process, to **discuss** a concept, to **evaluate** some data or to **derive** an equation. These are the tasks that the student actually does in order to demonstrate understanding, so it is these terms that should be used to express the learning outcomes.

Learning outcomes should:

- be written in the future tense;
- identify important learning requirements;
- be achievable and assessable;
- use clear language easily understandable to students.

For example when writing learning outcomes, it may be useful to use the following expression: **At the end of this module/course the student should be able to.....**

Then follow with an action verb. Useful action verbs include:

analyse, appraise, apply, calculate, choose, compare, contrast, create, criticize, demonstrate, derive, describe, design, develop, differentiate, discuss, explain, evaluate, extrapolate, formulate, identify, list, measure, name, plan, plot, postulate, predict, present, propose, recall, recognize, use, utilize.

By articulating outcomes in this way it should be made clearer to students what they are expected to be able to do. Learning outcomes may also help staff to decide whether they are assessing what they think they are assessing, and whether their assessment methods are appropriate. If a learning outcome is defined, be prepared to say how it is developed and assessed. There are no rules on how many outcomes are appropriate per lecture, course or credit point, and any attempt to standardize would be completely artificial. Some modules may have many outcomes that are fairly easily achieved and assessed. Other, perhaps higher level, modules may have fewer, more complex outcomes, which are more demanding to acquire and demonstrate.

Examples of learning outcomes from an introductory module on atomic structure are given below. The aims of the module may be to give students an appreciation of how models of the atom have developed and help them to recognize the importance of quantum mechanics in describing the modern view of the atom. All action verbs are highlighted in bold.

At the end of this module the student should be able to:

- **define** the terms *wavelength*, *frequency*, *amplitude* and *node*;
- **recall** the relative frequencies or wavelengths of the various regions in the electromagnetic spectrum;
- **describe** the Bohr model of the atom and **use** it to account for the emission line spectra of the H atom;
- **discuss** the limitation of the Bohr model;
- **use** the Rydberg equation to **predict** the wavelengths of electronic transitions;
- **describe** the concept of particle wave duality;
- **state** the Heisenberg Uncertainty Principle and **discuss** the ramifications of it;
- **describe** what is understood by the term *orbital*;
- **name** and **state** the relationships between the quantum numbers n , l and m_l .

2.2 Learning Outcomes Profile for Graduates in Chemistry and Chemical Engineering

The following, which is based on the EURACE reference framework of competences (<http://www.enaee.eu/>) and the Eurobachelor/Euromaster requirements, provides a generic description of learning outcomes that should be possessed and demonstrable by all graduates completing degrees at first and second cycles. They represent a clear statement of what a potential employer or graduate admissions tutor should reasonably expect. While traditional syllabi and assessment methods have focused almost exclusively on knowledge and understanding, it is now important that course descriptors make clear how all prescribed learning outcomes will be developed and assessed. Description of learning outcomes for any particular course, while meeting these general specifications, should also provide details of how the desired outcomes will be achieved. Action verbs are highlighted in bold for each of the learning outcomes listed below.

Knowledge and Understanding

*First Cycle graduates should be able to **demonstrate****:

- knowledge and understanding of the scientific and mathematical principles underlying their chosen discipline;

- a systematic understanding of the key aspects and concepts of their chosen discipline;
- coherent knowledge of their discipline including some at the forefront;
- an awareness of the wider multidisciplinary context of their chosen discipline.

*Second Cycle graduates should be able to **demonstrate***:*

- an in-depth knowledge and understanding of the principles of their chosen discipline;
- an awareness of the relevance of their chosen discipline in a wider multidisciplinary context.

** Individual course and module descriptors should make clear how such knowledge and understanding will be identified and validated.*

Intellectual Abilities

First Cycle graduates should be able to:

- apply their knowledge and understanding to **identify, formulate** and **solve** relevant problems using established methods;
- apply their knowledge and understanding to **analyse** the products, processes and methods of their chosen discipline;
- **select** and **apply** relevant analytical and modelling methods;
- use their knowledge and understanding to **develop** and **realize** strategies and designs to meet specified requirements;
- understand appropriate professional methodologies in order to **apply** them successfully in practice.

Second Cycle graduates should be able to:

- **solve** unfamiliar problems which are incompletely defined and have competing specifications;
- **formulate** and **solve** problems in new and emerging areas of their discipline;
- **use** their knowledge and understanding to **conceptualize** appropriate models and representations;
- **select** and **apply** innovative methods of problem solving;
- **apply** their knowledge and understanding to **design** solutions to unfamiliar problems, possibly involving other disciplines;
- use creativity to **develop** new and original ideas and methods;
- **display** professional judgement, when faced with technical uncertainty and incomplete information, to tackle complex problems.

Professional/Practical Skills

First Cycle graduates should:

- **display** appropriate laboratory and workshop skills;
- possess the ability to **design** and **conduct** appropriate experiments, **interpret** data obtained and **draw** pertinent conclusions;
- exhibit the ability to **select** and **use** appropriate equipment, apparatus, tools and methods;
- **demonstrate** an understanding of applicable approaches, techniques and methods and an appreciation of their limitations;
- possess the ability to combine theory and practice to **solve** scientific, technical and practical problems;
- possess the ability to **conduct** searches of literature and to efficiently **use** data bases and other information sources;
- possess ability to **reference** and **accredit** sources of information correctly;

- be able to **demonstrate** an awareness of the non-technical implications of their discipline.

Second Cycle graduates should be able to:

- **identify, locate** and **acquire** required data;
- **design** and **conduct** analytical, modelling and experimental investigations;
- **critically evaluate** the significance of new and emerging technologies to their areas of expertise;
- **critically evaluate** data and **draw** appropriate conclusions;
- **integrate** knowledge from a variety of fields and **handle** complexity;
- **demonstrate** a comprehensive understanding of applicable approaches, techniques and methods, and of their limitations;
- **recognize** and **consider** non-technical implications of the professional practice of their discipline.

Generic Graduate Skills (Transferable skills)

First Cycle graduates should be able to:

- **recognize** the need for, and have the ability to **engage** in independent, life-long learning and professional development;
- **function effectively** both as an individual and as a member of a team;
- use a variety of methods to **communicate effectively** both within their chosen discipline and with society at large;
- **display** awareness of the health, safety and legal issues and responsibilities associated with professional practice; **recognize** the impact that practice of their discipline may have in a societal and environmental context and **commit** to the ethics, responsibilities and norms of professional practice;
- **demonstrate** an awareness of project management and normal business practices including risk management and its limitations.

Second Cycle graduates should be able to:

- **fulfil** all the Transferable skill requirements of a First Cycle graduate at the more demanding level of Second Cycle;
- **work** and **communicate** effectively in national and international contexts;
- **function effectively** as leader of a team that may be composed of different disciplines and levels.

2.3 Specific Examples of Learning Outcomes

This section contains a variety of learning outcomes currently in use. These are, of course, merely examples to illustrate the range and structure of learning outcomes, and should not be taken as mandatory elements to be included in any new course documentation. For consistency, the outcomes are divided into the four categories identified in the previous section, action verbs are highlighted in bold and all learning outcomes listed should be preceded by, 'At the end of this module a student should be able to.....'

Knowledge and Understanding

- **describe** how reaction rates vary with concentration and temperature;
- **define** terms used in chemical kinetics;
- **describe** the arrangement of the elements in the periodic table and **identify** and **explain** the various relationships that can be found between them;
- **sketch** the five '3d' orbitals, **predict** how these will be split in compounds of various geometries, and hence **explain** the spectroscopic and magnetic properties of transition metal complexes;

- **recognize** functional groups, **name** mono-functional organic compounds and **construct** structural formulae from the systematic names;
- correctly **depict** the structure of organic compounds and **write** equations for their reaction;
- **describe, discuss** and **explain** common organic reaction mechanisms.

Intellectual Abilities

- **solve** qualitative and quantitative defined problems in basic areas of chemistry/chemical engineering by **selecting** an appropriate method from those covered in lectures;
- **solve** unfamiliar qualitative, quantitative and open-ended problems by developing a strategy and identifying relevant data;
- **critically evaluate** the principles of green chemistry;
- **critically evaluate** how chemistry can be applied to provide a supply of sustainable feedstocks;
- **formulate** priorities when taking complex decisions;
- **design**, starting from a template, a procedure describing an action;
- **determine** the point group for any given chemical structure and **use** character tables to explain spectroscopic properties.

Professional/Practical Skills

- **devise** one- and two-step syntheses for simple organic compounds, and **ascertain** the identity and purity of synthesized compounds using established analytical methods;
- **plan** and **carry out** several-step syntheses for organic compounds;
- **select** appropriate protective groups and methods for their removal for specified syntheses;
- reliably **present, record, analyse** and **discuss** experimental results;
- **work** safely following specified procedures and regulations;
- **control** and **monitor** chemical/industrial processes using computers;
- **interpret** x-ray diffraction data obtained from solid samples;
- **write** a detailed report of an extended research project, **interpreting** data and critically **evaluating** outcomes;
- **select, apply** and **interpret** statistics to present and analyse data;
- **operate** equipment, materials and resources under standard conditions so that product remains within specifications.

Generic Graduate Skills

- **recognize** and **take account of** input from colleagues;
- **communicate** clearly and respectfully with peers and superiors;
- **identify** and **articulate** own professional strengths, weaknesses, goals, preferences and aspirations, and **devise** strategies to achieve the stated goals;
- **demonstrate** effective time and task management;
- **plan, develop** and **evaluate** innovative ideas and new ventures in relevant contexts;
- **work effectively** as a member of a team **displaying** the skills of listening, negotiating and leadership.

3. Programme and Course Design

The context for an outcomes-based approach, as well as an overview of desired graduate attributes associated with chemistry and chemical engineering qualifications, has been presented in the preceding sections. The global trend towards defining qualifications in terms of a set of expected learning outcomes, or desirable graduate

attributes, has presented higher education institutions with significant new challenges. The main requirements for any outcomes-based qualification are a clear understanding of the goals and objectives of the programme, and teaching strategies that are able to support the development of the required competencies, coupled with assessment procedures capable of reliably monitoring whether the established targets are being met, or not. Hence, Higher Education Institutions will need to ensure that the learning programmes that they deliver provide:

- A coherent assembly of discipline specific and complementary knowledge areas, with appropriate embedding and meaningful integration of required skills and values.
- Adequate opportunities for the development, demonstration and assessment of required competencies, from the level of novice up to the desired level of proficiency, as the student progresses through the programme.
- An increase in the level of cognitive, affective, and psychomotor complexity from first year to final year, to ensure effective preparation for the world of professional practice, and lifelong learning.

The purpose of this section is to present key points to be considered in the design, development and delivery of these qualifications. The processes associated with the development and delivery of an outcomes-based qualification will be presented as a three-stage process:

Stage 1: Description of the Qualification:- Establishing the purpose of the qualification, and the expected competencies of graduates from the programme.

Stage 2: Structuring the Curriculum:- Establishing the content and learning activities required to support the achievement of the outcomes required.

Stage 3: Programme Delivery:- Providing the teaching, learning and assessment strategies that will facilitate the development and assessment of the outcomes associated with the qualification.

Each of these stages is considered in more detail in the following sub-sections and a simple overview of the key elements presented is shown in Figure 3.

3.1 Stage 1: Description of the Qualification/Course:

This is a complex process which should involve all relevant stakeholders, with the key objective of determining the purpose and desired outcomes of the qualification. It will involve performing a functional analysis of typical occupational roles that graduates of the programme are likely to occupy. The functional analysis will identify the skills, knowledge and competencies required to develop a graduate with the desired attributes and abilities. It is expected that these attributes/competencies should enable a graduate to:

- Efficiently perform a variety of profession related tasks.
- Function professionally in a range of roles and situations, and
- Adapt to a transforming and evolving world of work.

The complexity stems from the perceptions and interests that the various stakeholders bring into the process. Each industry or cluster of industries, the professional bodies and learned societies, research organizations, civil society, and educators may have different expectations of the qualifying graduates. Hence, all inputs obtained must be analysed, assessed and prioritized, in an attempt to define clearly the desired and expected outcomes for a qualification. Stage 1 provides the basis for setting the goals and objectives upon which the curriculum will be

structured. For the disciplines of chemistry and chemical engineering, this process has been extensively carried out by various Tuning Educational Structures, Professional Societies and Registration Bodies in Europe. Desired outcomes for the various qualification cycles have been established, and some of the noted outputs are:

- Reference Points for the Design and Delivery of Degree Programmes in Chemistry (website: www.ec2e2n.net)
- The Eurobachelor and Euromaster descriptors by the European Chemistry Thematic Network (ECTN) (website www.ec2e2n.net)
- EFCE Recommendations for Chemical Engineering Education in a Bologna Three Cycle Degree System. (http://www.efce.info/Bologna_Recommendation)
- European Network for Accreditation of Engineering Education (ENAAEE). The EURACE quality label to higher education engineering (website: www.enaee.eu)

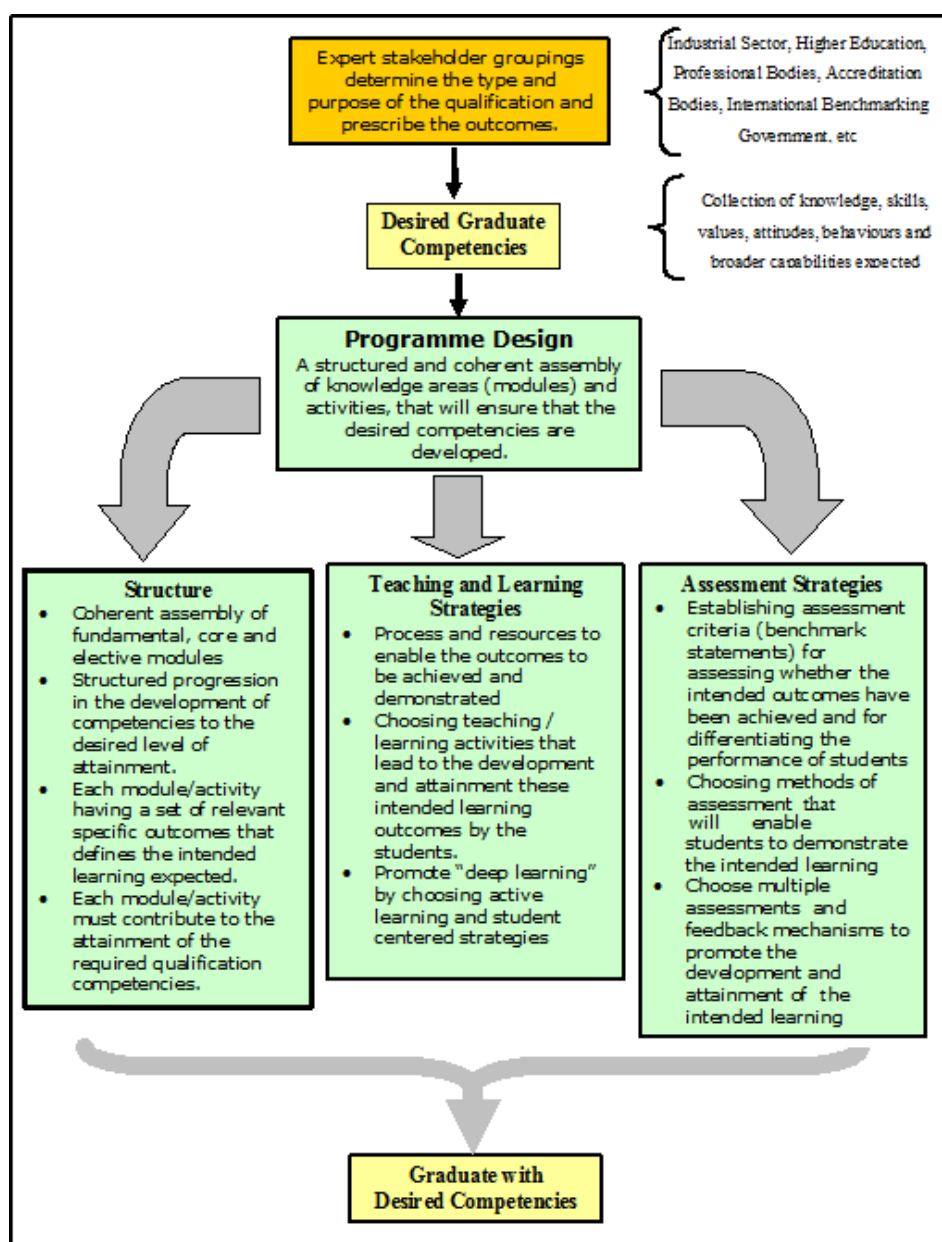


Figure 3. An overview on an outcomes-based curriculum design process (Chemepass, 2009).

3.2 Stage 2: Structuring the Curriculum:

Once the learning outcomes for a course have been formulated, curriculum designers can turn their attention to the issue of structuring the learning process. Whenever a learning outcomes approach is adopted the curriculum must be concerned, not only with the content to be learned, but also with the behaviour (skills, abilities, attitudes) to be developed. Creating a learning programme to meet the specification of the qualification determined in stage 1 requires effort in each of three domains:

- Identifying and defining measurable learning outcomes for the various knowledge areas associated with the qualification - this will establish the indicative knowledge area content for the programme;
- Identifying the teaching and learning methods that will be used to deliver the specified content, and facilitate the development of required outcomes to the desired levels, and
- Identifying the assessment methods that will be used to determine whether, and how well, these outcomes have been achieved.

In the curriculum development process, it is important to ensure that syllabi, learning objectives, and teaching and assessment methods, result in a coherent curriculum in which all components have well-defined and interconnected roles in achieving course objectives. In stage 1, the stakeholders and discipline experts will have identified and recommended the key knowledge areas needed to contribute to a relevant qualification. Typically, the recommended knowledge areas for a chemistry or chemical engineering programme:

- Should have a *coherent core* of mathematics, natural sciences and fundamental discipline specific sciences (e.g. engineering sciences) to provide a viable platform for further studies and lifelong learning. The coherent core should enable development both within the traditional discipline and in related emerging fields.
- Should include some complementary studies which: (a) are essential to the practice of the discipline, including economics, the impact of technology on the environment and society, and effective communication; and (b) broaden the student's perspective in the humanities and social sciences in order to understand the world in which the discipline is practiced.
- Could also include specialist study which may take on many forms including further deepening of a theme in the core, a new sub-discipline, or a specialist topic building onto the core.

Organization of the content for a curriculum or course is likely to begin with the identification of the knowledge which will be required to function effectively as a graduate of the discipline, and any prerequisite knowledge that will be needed before a student can enrol on the course. The required knowledge must then be structured to fit into a logical pattern. In deciding on content and programme structure, the following points should be considered:

- **Content:** Factors to consider in deciding on the content include relevance, breadth, depth and structure.
Relevance: Knowledge areas should only be included in a programme if they provide an effective contribution to either the curriculum area, or to the programme outcomes. If they are essential contributions, then they should be included in the core modules, otherwise they may be incorporated within optional modules. A second aspect of relevance is that the subject matter should be current, and consideration must be given to

the developments occurring in a field of knowledge.

Breadth and Depth: Breadth applies to how broad the content is *i.e.* upon how many concepts the content touches. Depth, on the other hand, refers to the degree to which any one concept is explored. A great depth means that the individual concept has been explored very thoroughly (from first principle derivations to complex applications).

Structure: The key concepts of a discipline should be developed early and carried through the curriculum, building from the simple to the complex.

- **Defining the measurable learning outcomes for the various knowledge areas:**

The learning outcomes will include those specific to knowledge areas, professional practice skills and generic skills. Suggestions on how to define measurable learning outcomes for each of the courses/modules/knowledge areas have already been discussed in sections 2.1 and 2.2 of this document.

- **The sequence of knowledge delivery:**

- The sequence in which topics are taught and skills developed is based on assumptions, experience and knowledge area expertise on how required discipline knowledge and skills are best accumulated.
- Consideration must be given to the interdependence and prerequisite nature of the various elements of the curriculum.
- Students must learn to apply fundamentals to increasingly more difficult problems over the duration of the programme. Topics should be treated at a basic level initially and at progressively more advanced levels subsequently.
- Development of a competence to the required level is not likely to be achieved as a one-off event; rather, several opportunities will be needed throughout the curriculum for the development of key competencies.

Experience of both teaching and the knowledge area to be taught, will be important when deciding how best to structure teaching and assessment.

3.3 Stage 3: Programme Delivery:

The aim of the education process is to find efficient ways to develop and assess a diverse set of qualification competencies. Hence, clear understanding of programme goals and objectives, teaching strategies to develop the required competencies, coupled with assessment procedures to indicate whether established targets are being met, are integral components of any coherent educational process. A basic knowledge of theories of learning (Byers and Eilks, 2009) can provide insight into understanding how students learn, thus improving the design of both curricula and the learning, teaching and assessment (LTA) procedures to be adopted. Such considerations are particularly important during the design of syllabi to enable required learning outcomes to be achieved. This section provides a brief introduction to the various factors that should be considered in the delivery of an outcomes-based course.

Starting with the assumption that deep learning, which seeks lasting mastery over a subject, is much more desirable in science and engineering education, than shallow learning, which is merely designed to pass academic assessments, educators must seek appropriate LTA strategies to encourage and facilitate deep learning. The implementation of learning strategies that actively engage a student is likely to

promote greater knowledge, understanding and skill development and, also present suitable opportunities to measure competencies. We all tend to remember the details of our research or design project, and laboratory experiences, much better than we remember the specifics of a particular lecture. In general methods of active learning motivate students and encourage them to take more responsibility for their own learning.

Brown (2001) noted that the knowledge of different types of cognitive demands is an essential ingredient in designing learning and assessment strategies. To encourage a deep approach to learning, it has been suggested that the use of the higher levels of Bloom's Taxonomy (Krathwohl, 2002) or Biggs' SOLO Taxonomy (Biggs *et al.*, 2007) should be required by assessments. Bloom and his co-workers developed taxonomies for educational objectives, which are invaluable for the assessment of Outcomes-Based Education (OBE). They are used in the formulation of objectives and the development of criteria to establish whether learners have actually attained acceptable standards with respect to the desired learning outcomes. Detailed descriptions of the above learning taxonomies are extensively available in the literature. A summary of these taxonomies with some relevant science and engineering scenarios has been published by Kennedy *et al.* (2007).

The effectiveness of learning also depends upon the teaching style of the lecturer and the learning style of the student. There are various learning theories and models on styles of learning. Felder and Brent (2003) conclude that it does not matter what model is used to assess students; rather, it is important that instructors understand that students tend to learn differently and that teaching to support the full spectrum of learning styles tends to improve students' learning, satisfaction with their instruction, and self-confidence. Felder and Brent, therefore, suggest that instructors should use a variety of teaching methods, such as group problem solving, brainstorming activities, design projects, and writing exercises, *etc.* in addition to formal lecturing.

4. Some Concluding Remarks

The case for an outcomes-based approach to higher education is undoubtedly strong (Watson, 2002), however, it must be admitted that serious misgivings concerning the value of such approaches have been raised. Hussey and Smith (2002), while acknowledging the potential usefulness of learning outcomes, suggest that ambiguity is always likely to arise when considering exactly what is required to successfully meet a particular learning outcome, and conclude that the apparent clarity, explicitness and objectivity, claimed by supporters of outcomes approaches is therefore likely to be largely spurious. They suggest that the emergence of ideas, skills and connections that were unforeseen, even to the teacher, represents one of the most valuable features of higher education and argue, therefore, that far from promoting learning, an over-emphasis on planned outcomes may in fact inhibit it, by squeezing out such emergent learning outcomes (Meggison, 1996).

Effective assessment of learning outcomes clearly provides a problem that traditional assessment methods will not always be able to solve, and a range of approaches is likely to be needed to match assessment with specific outcomes (Bennett and Wilson, 2009). It is difficult to see how we can assess all learning outcomes individually without over-assessing our students. It will, therefore, frequently be necessary for

several learning outcomes to be assessed through a single assessment task. This is likely to demand both thought and ingenuity from academic staff.

It is clear that effective implementation of an outcomes-based approach is a far from simple task. However, given the increasing importance of accountability and employability throughout higher education, it is surely important that recognition of the difficulties is used constructively to improve teaching provision, rather than as an excuse to do nothing.

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