The Teaching of Safety in an Undergraduate Chemical Engineering Programme

Pat Kennedy Lecturer Cork Institute of Technology

The Paper describes in detail how Safety is fully integrated into an Undergraduate Degree Programme in Chemical and Biopharmaceutical Engineering. As well as being taught explicitly in dedicated Safety Modules, safety is fundamental to modules at all levels within the four year MEng Accredited Programme at Cork Institute of Technology (CIT).

From their very first day in College, students are constantly reminded that Safety is a basic requirement of a Professional Engineering career. It must be considered "ab initio" rather than "in fine", when a design has (allegedly) been completed.

Where a particular topic is being taught, its safety implications are emphasised. The application of the principle in question is illustrated with examples from the various industries where Departmental Staff have worked before entering academia as well as case studies such as Texas City (CSB 2007), Flixborough (HSE 1975), (Mannan 2012), Bhopal (Crowl and Louvar 2011), Buncefield (IChemE 2014) and sources such as the Process Safety Beacon (AIChE 2001-2015).

Where a Module is assessed partly or fully on the basis of a submitted Report or Project, the Project Brief emphasises the requirement for a Risk Assessment to be performed and submitted.

Rather than being covered in a dedicated Module, Inherent Safety is dealt with in a similar manner. Students are shown how the selection of a Processing Route, Processing Conditions (Pressure, Temperature), a Raw Material or a Solvent based on the principles of Inherent Safety at as early a stage as possible in a project will make subsequent provision of Safe Working Procedures much easier. Again, Case Studies such as Bhopal are used to illustrate this point.

Beginning in First Year, students must complete a detailed Risk Assessment before all Laboratory Practicals based on the standard procedure

- Identify the hazards.
- Assess the Risk.
- Identify and Apply Controls.
- Review and, if necessary Revise.

This requirement is continued at all stages of the course, culminating in the Research Project in Final Year.

The formal Risk Assessment techniques - FTA, FMEA, and Hazop – are covered in formal classes but must also be used in the Students' Design Project in Final Year.

In this way, while only five Credits out of the course total of 240 have a formal safety title, our graduates are thoroughly inculcated with a sound understanding of the principles of safety which they can apply to their future careers.

Cork Institute of Technology (CIT) (Founded in 1974 as Cork Regional Technical College) is a Third Level college, situated in Cork on the south coast of Ireland. It offers undergraduate and post graduate courses to PhD level in Business, Science, Computing, Engineering, Fine Art and Design, Music, Humanities, Social Studies, Education and Maritime Studies.

The Department of Process, Energy and Transport Engineering is in the School of Mechanical, Electrical and Process Engineering and the Faculty of Engineering and Science. It offers Degree Courses in:

- Building Services Engineering,
- Sustainable Energy Engineering,
- Transport Management and Technology and
- Chemical and Biopharmaceutical Engineering.

The BEng Degree Course in Chemical and Biopharmaceutical Engineering is a 4-year honours degree, consisting of 240 credits in the European Credit Transfer System (ECTS). The course is accredited to Level 8 on the National Qualification Framework and at MEng level by IChemE. The first cohort of students graduated in 1983.

Details of the course are available on the CIT website (CIT 2016). As can be seen, among the Programme Outcomes are:

- "the ability to design chemical, biochemical, pharmaceutical and process plants from conceptual design through to commissioning and operation, to develop processes to achieve a desired product taking account of safety."
- "the ability to address an unstructured problem, and execute work which requires critical evaluation and decision making skills; the ability to develop and evaluate alternatives for a particular operation based on ……safety"
- "the ability to manage a project through all stages addressing safety"

- "an appreciation of the need for high ethical and professional standards; a recognition of the priorities and role of sustainable development; an ability to analyse the interaction of process, product and plant with the environment ensuring that appropriate standards of safety and environmental concern are integral to all activities"

These Programme Outcomes are addressed throughout the course, either by formal instruction in specific Modules using Case Studies or less formally using examples from everyday life or industry where the topics being studied have safety implications.

The majority of students enrol on the course after completing their Leaving Certificate Examination, a State Examination taken at age 18 approx. Students attend on Campus for a day-long induction in the week before formal lectures begin. Part of this Induction is an introductory lecture in the Chem Eng Department, during which the role of the Chemical Engineer is described.

During this talk, the students are informed, in no uncertain terms that, throughout their Professional careers, they will be responsible for the safety of all who might be affected by the equipment, materials or processes relevant to any design they have undertaken. In brief, they are told: "It is the duty of a Chemical Engineer to retire, not having killed anyone."

First Year

All First Year students in CIT study a common module, Creativity, Innovation and Teamwork (CI&T). While this Module is studied by all, it is delivered by individual Departments as part of their own programmes. As such, each Department is free to tailor the Module to the individual requirements of its Programme. As part of this Module, all Chemical Engineering students receive training in the use of Fire Extinguishers. The theory of Fire is covered (its causes and methods of prevention, different types of extinguisher, the suitability of an extinguisher for particular classes of fires) and the individual student receives practical experience in the use of an extinguisher. The CIT Emergency Procedure is also covered, including a "live" alarm and evacuation drill.

The CI&T module informs the student of the various career pathways that are available in Chemical Engineering. It is emphasised again that no matter which pathway or combination of pathways that the student follows, safety will be an integral part. Indeed career progression will often depend on a good safety record. Case studies of Chemical Engineering projects, both successful and otherwise are used to emphasise this point.

The first formal instruction in Chemical Engineering received by the students is Process Principles and Design 1 (PPD1) One of the Learning Outcomes of the Module is "On successful completion of this Module, the learner will be able to recognise and integrate the importance of ...safety considerations in good process design. Identify ethical issues confronting engineers" (CIT 2016). Students are shown how decisions made at the initial stages of a Process, such as the selection of a Process Route, or Raw Materials, will influence the safety of process and those affected by it. The Sevin Process as operated at Bhopal illustrates this concept perfectly as outlined by Crowl and Louvar (2011)

The Modules, Engineering Chemistry, Engineering Physics and Biomolecules and Cells are essentially a re-treatment of the material already learnt by the students at second level but, as the titles suggest, with an emphasis on content to solve engineering problems. The hazards arising from the various properties studied (reactivity, corrosivity, flammability, acidity or basicity, gravity, Pressure, infectivity etc.) are emphasised at every opportunity.

The Process Engineering Labs 1 Module, as the name suggests, allows the students to put the basic concepts encountered in the Classroom into practice in a Laboratory environment. At the start of the first Laboratory class, the students are shown around the Laboratory and have the various safety features therein (Safety Showers, Eye Baths, Emergency Exits, First Aid Spill Kits) pointed out to them. Before beginning any experiment, each student must conduct a Risk Assessment. The Risk Assessment is in the standard format:

1. Identify the Hazard
2. Assess the risk
3. Identify and apply Controls
4. Review and, if necessary Revise.

Hierarchy of Controls
Design
Replacement
Isolation
Local ventilation
General Ventilation
Good Housekeeping and hygiene
Limited Exposure
Personal Protective Equipment

Table 1 Hierarchy of Controls.

It must be included in the Laboratory Report submitted by each Student for marking. The Controls identified must follow the hierarchy as set out in Table 1. While PPE is made freely available and must be worn where appropriate, students are reminded at every opportunity that PPE is the last option that must be considered, only to be used when all other controls have been assessed and found wanting. In First year, the students are closely guided by the Academic staff and Laboratory Technicians when conducting these Risk Assessments. As the students progress through the programme, the Risk Assessments become more "open ended." The level of guidance is reduced as the students become more experienced, but in all cases, no practical may be commenced until the risk assessment is reviewed and accepted by the staff member delivering the module. While the experiments are under way, staff members monitor the students to ensure compliance with the control measures set out in the Risk Assessments. Should a student

deviate from the controls, a disciplinary procedure involving in order, verbal warnings, written warnings, removal from the Laboratory and ultimately expulsion from the Module may be invoked.

In the Second Semester, the Process Principles and Design 2 Module builds on the material covered in the first semester. One of the learning outcomes of this module is " On successful completion of this Module, the learner will be able to identify and define the basic concepts involved in Process Safety and the correct philosophy underlying safe process design." (CIT 2016)

The Organic Chemistry Module, is taught in a similar manner to the "Engineering Science" Modules from semester 1. The effect that operating Pressures and Temperatures will have on yield and purity of product is described as well as how the use of catalysts can bring about the same results at lower Pressures and Temperatures rendering the process safer.

Second Year

The Chemistry for Chemical Engineering Module builds on the previous Chemistry Modules again stressing the importance of Raw Material and Route selection to reduce the hazards of a process.

Equipment Design covers the design of Pressure Vessels, an integral part of Plant Safety. Compliance with Codes and preservation of the integrity of vessels, equipment and linking pipework is emphasised. The dangers of uncontrolled modifications and deterioration of plant are addressed.

Transfer Processes 1 deals with the fundamentals of Fluid Mechanics and Heat Transfer. Safety related topics include the necessity for Pressure Relief on the discharge side of Positive Displacement Pumps and the desirability of routing the corrosive, hot fluid through the tubes of a Heat Exchanger, where possible. "Bernoulli" calculations on installations involving Quench and Dump Vessels are also covered.

In the Second Semester, the Control and Instrumentation Module emphasises that the action of a Control Valve (Fail Open or Fail Closed) must be decided on the basis of the position that ensures safe operation. In general where a Control Valve controls the addition of energy into a system, it must fail closed. Where it controls the removal of energy from a system, it must fail open. Of course, from an early stage in their Chemical Engineering education, students are shown that blanket generalisations can be dangerous so each situation must be analysed on its individual merits and an appropriate decision must be based on the analysis.

Equilibrium Separations considers some common separation methods – which typically involve flammable, toxic material and their processing at non-ambient conditions. This permits an emphasis on the selection of chemicals which may be processed under conditions that are less likely to leak or substances that will not degrade with temperature.

The Process Engineering Labs 2 Module is similar to the First Year Laboratory Module. Again, the students must conduct a Risk Assessment for inclusion in the Lab Report before commencing work on the experiment.

The Biopharmaceutical Engineering Module deals with the Regulatory Environment in which facilities must operate. While the major emphasis of the various world-wide Regulatory bodies will be on quality issues, these necessarily will have an influence on Patient safety and on control of containment.

Third Year

The Product Design Module requires the Students, in Groups, to compile a Design of a consumer product of their own choosing. Product Safety will be a fundamental requirement of the design.

The Fluid Properties Analysis Module as the title suggests, deals with the physical properties of Liquids and gases and how these will change with variations in Temperature and Pressure. The relevance of these relationships to the safe design of equipment is demonstrated.

In the Chemical Reactor Engineering and the Bioreactor Design Modules, the relevancy of Reaction Kinetics and rates of reaction to Process Safety is shown. Case studies where Kinetics Data were not fully understood with disastrous consequences are studied.

The Process Waste Management Module requires students, in groups, to:

- "Formulate a waste treatment strategy to treat the wastes arising from a selected industrial process using Best Available Techniques (BAT)." (CIT 2016).
- "Construct an IPPC (or IED) licence application based on design calculations for the waste treatment process train(s) selected."

This Module is assessed in the main on a submitted report which is required to place particular emphasis on

- The hazards arising from the waste, the treatment methods and the treated waste.
- The "Pollution Prevention" element of the IPPC.

Students are shown that in a similar way to the way that selection of the Processing Route will have a major effect on the nature and the quantity of the waste produced, the selection of the treatment technique will influence the both the safety and the effects on the environment of the treated waste.

In the second semester of Third Year, the Students study Process Design which is split between Safety and Economics. This is the first Module where Safety is formally addressed. The safety-related Learning Outcomes of this Module require the student to:

- Identify the causes of fires and explosions in the workplace.
- Conduct a workplace Fire and Explosion Hazard assessment
- Specify fire-fighting systems and equipment for various hazardous workplaces.
- Create workplace strategies so as to minimise fires and explosions.

(This Module and the EHS Risk Management Module in Year Four (see below) form the basis of the Process Safety Module, a joint venture between CIT and Pfizer Pharmaceuticals (Ireland)Ltd as described by Kennedy et al (2015). It is planned to replace these Modules with the unified Process Safety Module beginning in the Academic Year 2016-7.)

The Process and Properties Analysis Module continues the work done in the Fluid Properties Analysis Module from Second Year. It introduces the students to Property Prediction Software Packages such as AspenPlus ®. The care that must be taken to validate data from such packages before relying on them to perform safety related calculations such as the sizing of Emergency Relief systems is stressed.

The Transfer Processes 2 Module continues from the Transfer Processes 1 Module, including such safety related issues as the design of Column Reboilers, where the liquid level must never be allowed to fall below the level of the tubes and the need to fully understand compressible and two-phase flow in the context of Pressure relief.

Process Engineering Laboratories 3 is similar to the Laboratory Modules from the previous years. The experiments performed are less structured, with the Students being given instruction in general terms on what it is desired to achieve. Again, the students must conduct a Risk Assessment for inclusion in the Lab Report before commencing work on the experiment. This Risk Assessment is performed in a class separate from the scheduled Laboratory session and must be approved by the Laboratory Supervisor before Laboratory work is commenced.

Third Year is completed by a full-time five-month Industrial Placement. The purpose of this placement is to re-inforce the material learned by the student in the first three years of the course. Obviously, the understanding of Safety and the requirement to adhere to any Safety rules and Regulations is a major part of working in industry. The Safety induction undergone by the students in their placement location will reinforce the material with which the students will have become familiar during their initial three years of study.

Final Year

EHS Risk Management, is split between Safety and Environmental Risk. Safety Management, Probability Assessment, Consequence Analysis and Risk Assessment are covered as well as formal assessment techniques such as Fault Tree Analysis, Failure Mode and Effect Analysis and Hazard and Operability Studies. Case studies such as Texas City (CSB 2007), Flixborough (HSE 1975), (Mannan 2012), Bhopal (Crowl and Louvar 2011), Buncefield (IChemE 2014) and sources such as the Process Safety Beacon (AIChE 2001-2015) are used throughout the Module to reinforce the topics covered and relate them to actual real-life situations.

The Research Project (10 Credits) and the Design Project (15 Credits), undertaken by all students, are the two “Capstone” Projects of the course. Students bring together all of the learning from their previous years as well as performing additional research.

The Research Project is often conducted at the company where the student completed the Work Placement Module. During this Module, an area where research would be useful to the host company is identified, in conjunction with the host and a proposal is drawn up. This project is often in a Safety related area but if not, there will still be a requirement to conduct a rigorous Risk Assessment of the project in advance of its commencement.

Where it is not possible to base the Research Project “on-site”, it is conducted in the CIT Chemical Engineering. Laboratory. Again a rigorous Risk Assessment of the project in advance of its commencement is required.

The Design Project is carried out in the second semester of Final Year. It involves a detailed design of a Manufacturing Facility and is divided into five sections. The sections with Safety implications are as follows:

- Section 1:- Preliminary evaluation of alternative processes and selection of desired process based on an evaluation of technical, economic, safety, environmental, ethical and social issues
- Section 3:- Detailed design of specified items of equipment, e.g. reactor, mass transfer item, heat transfer item, fluid transfer item.
- Section 4:- Detailed Safety, Environmental and Economic Evaluations, including operating strategy, HAZOP and control strategy.
- Section 5:- Special Item

Sections 1, 2 and part of Section 4 are done in a Group. Section 3, part of Section 4 and Section 5 are done individually.

Section 5 regularly, but not always involves a Safety-related topic.

Feedback from Graduates

CIT prides itself in maintaining contact with its graduates during their professional careers. IChemE meetings, dinners conferences and other activities allow for informal contact between Chem Eng staff and graduates. Regularly at such gatherings, reference is made by graduates to topics that have been covered in College which are relevant to their careers. Invariably safety topics are included in such discussions.

Conclusion

On first examining the list of Modules making up the Degree Programme (CIT 2016) it may appear that Safety is only covered in a part of two of the forty four Modules, totalling 5 credits (2 times 2 ½) out of a total credit count of 240. Nothing could be further from the truth. As described above thirty one of the forty four Modules have safety implications which are emphasised at every opportunity, leaving graduates of the Course thoroughly familiar with the integral part that Safety plays in the professional career of the Chemical and Biopharmaceutical Engineer. Graduates of the course will be more than adequately equipped to fulfil their duties to "exercise all reasonable professional skill and care to prevent avoidable danger to health or safety" as required by the IChemE (2015)

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