CHEMICAL ENGINEERING TRANSACTIONS

VOL. 77, 2019

A publication of
AIDIC
The Italian Association of Chemical Engineering
Online at www.cetjournal.it

Guest Editors: Genserik Reniers, Bruno Fabiano

ISBN 978-88-95608-74-7; **ISSN** 2283-9216

DOI: 10.3303/CET1977067

Improve Process Safety in Undergraduate Education

Zsuzsanna Gyenes

Insitution of Chemical Engineers Safety Centre, Davis Building Railway Terrace, Rugby CV21 3HQ, United Kingdom
zgyenes@icheme.org

The IChemE Safety Centre (ISC) has undertaken some work to develop a list of desired learning outcomes for undergraduate chemical engineers. The project consisted of determining industries expectation of process safety education and presenting those expectations to a range of universities. That consultation led to a document stating the expectations as well as highlighting some information and resources to assist universities in reaching the goal. A benchmarking exercise was launched by the ISC to understand how well these learning outcomes fit into the existing curricula of contributing universities. The overall scope of the exercise is to review each element listed in the guidance document and see if they fulfil the criteria and objective of any undergraduate Chemical Engineering course. The participants assess the learning outcomes regardless of whether process safety is delivered as single subject or integrated in other courses. The learning outcomes includes four sections around Process Safety. Three of them cover classroom learning, meanwhile the last section characterises how Process Safety is applied in practice, for example laboratory activities, design projects and industrial training placements. This paper discusses the outcome of the benchmarking exercise; it presents whether the learning outcome can be applied and serve as a complete teaching package in Process Safety as a guidance. Universities are welcome to decide if the document supports the education and serves as a good reference or they need additional information/guidance to complete such course.

1. Introduction

The IChemE Safety Centre (ISC) has undertaken some work to develop a list of desired learning outcomes for undergraduate chemical engineers. The project consisted of determining industries expectation of process safety education and presenting those prospects to a range of universities. That consultation led to a document (ISC, 2018) stating the expectations as well as highlighting some information and resources to assist universities in reaching the goal. The concept of the learning outcomes supports the ISC six functional approach to process safety published in the Process Safety and the ISC – a framework document in 2014 (ISC, 2014).

The ISC six pillars are the followings:

- knowledge and competence;
- engineering and design;
- systems and procedures;
- assurance;
- human factors and
- culture.

When developing these learning outcomes, it was decided to lay out the expectations across four categories:
A. Process safety overview
B. Process safety in design
C. Guidelines for process safety risk assessment and
D. Process safety in practice.

Paper Received: 1 March 2019; Revised: 22 April 2019; Accepted: 30 June 2019

Please cite this article as: Gyenes Z., 2019, Improve process safety in undergraduate education, Chemical Engineering Transactions, 77, 397-402 DOI:10.3303/CET1977067

Sections A, B and C apply largely to classroom learning. Section D applies to practical application within the undergraduate course, and this document also provides learning guides on how the practical application could be achieved.
A benchmarking exercise was conducted involving sections A to C by the ISC to understand how well these learning outcomes fit into the existing curricula of contributing universities.

2. The benchmarking exercise

2.1 The scope

The scope of the exercise was to test each element listed in the guidance document and see if they fulfil the criteria and objective of any undergraduate Chemical Engineering course.
Participants assessed the learning outcomes regardless of whether process safety is delivered as single subject or integrated in other courses. Sections A, B and C were reviewed together, meanwhile the practical Section D was optional and it is not part of the evaluation. While Sections A-C represent classroom learning, Section D characterises how process safety is applied in practice, such as laboratory activities, design projects and industrial training placements. It is practical learning implemented through a (Process) Safety Management System. The group was asked to provide input on Section D if they have such a program in place.

2.2 The benchmarking criteria

Departments of Chemical Engineering of eight universities from all over the world, supporting members of the ISC took part in the benchmarking initiative. Their task was to first assess if they already teach any of the Sections A to C of the ISC learning outcomes document. In case those subjects or some of them are within the curricula of the university, they looked at how many gaps they could identify and close. For universities where the program does not include the learning outcomes they needed to teach the three topics in their class. After teaching the items listed, they needed to answer to the benchmarking questions. The questions assisted in evaluating the three sections whether they are relevant, useful and teachable in the undergraduate course. If participants thought that the questions would not help or not efficient, they could suggest other elements or possible corrections.
Based on their experience, participants had to evaluate if the learning outcomes topics are the right way to teach process safety or there are obstacles/limitations in teaching them (lack of resources, such as open literature, guidance documents etc.).

2.3 Benchmarking topics

A set of questions linked to Sections A to C of the guidance document assisted participants in the analysis. The aim with the answers was to provide a comprehensive summary about each section of the learning outcomes. To get the most out of the answers, participants could give their complete view about the section and their conclusions as free text.
Table 1-3 below show the expectations laid out in the Learning outcomes guidance document. Participants were invited to answer the questions linked to these topics, generated by the ISC and assess their effectiveness in teaching process safety.
Table 1 contains information about process safety in general. The objective of Section A is to understand if students are familiar with the term process safety, whether they see the difference between process and personal safety and know the concept of process safety management systems.

Table 1 Section A – Process Safety Overview (A1-A3)

Section A	Process Safety Overview
A1	Define the main concepts of process safety and describe the benefits of process safety to an organization and to society.
A2	Describe the similarities and differences between process and personal safety (sometimes referred to as “OH&S” – Occupational Health and Safety).
A3	Describe the main elements of a Process Safety Management (PSM) System.

Table 2 looks for information whether students know the concepts of inherently safer design.

Table 2 Section B – Process Safety in Design (B1-B3)

Section B	Process Safety in Design
B1	Define the concepts of inherent safety and list typical approaches to inherently safer process design.
B2	Describe the benefits of multiple barriers and list typical barrier types for controlling various process excursions.
B3	Compare the advantages and disadvantages of risk-based design versus code/standard-based design in the overall PSM framework.

Table 3 provides guideline for process safety risk assessment.

Table 3 Section C – Guidelines for Process Safety Risk Assessment (C1-C5)

Section C	Guidelines for Process Safety Risk Assessment
C1	Describe how risk assessment steps apply to process safety hazards and define the main concepts related to process safety risk assessment including protection layers, threats, consequences and effects, etc.
C2	Identify various process 'hazards' and develop 'risk' phrases in terms of loss of control of hazards, including identification of: • process hazards and the physics, chemistry, biology of the hazards • the potential consequences of a failure to keep them contained/controlled • threats to containment of hazards • prevention and mitigation controls through the hierarchy of controls model.
C3	Define the main concepts of common process hazard analysis tools. Compare qualitative and quantitative risk assessment techniques, their uses, benefits and limitations. Perform a hazard identification/ risk assessment for a process safety case study.
C4	Describe the concepts of As Low As Reasonably Practicable or / So Far As is Reasonably Practicable and describe the steps required to demonstrate that a risk has been reduced ALARP/SFARP (depending on jurisdiction).
C5	List typical factors that contribute to barrier effectiveness and explain the role of critical activities like monitoring, inspection and maintenance in managing barrier effectiveness.

2.4 Analysis

Participants reviewed the guidance document and provided their respond within six months. The analysis below shows the feedback from the universities took part in the benchmarking exercise.

Section A

Participants were asked if they teach Process Safety within the Chemical Engineering course and if so, is it delivered as a single course or integrated. All participating universities teach process safety, four teach it as a single course. Two universities responded that they teach the subject as both single and integrated. The choice “both” means that in case of one participant there is an obligatory course, and it is a single subject and electives are available in other courses. Meanwhile, at another university the stand-alone course in third year is compulsory but so are the other introductory courses in lower years, they are not electives. The second university that teaches process safety as both single and integrated explained that it is part of two modules.
Another question addressed if the course covers all elements identified within Sections A1, A2 and A3. If not, what gaps were recognised by the participants. According to the eight universities their course covers all sections but not necessarily taught within one year.
Based on the feedback, all topics covered by the section adequate and complete and there are no additional themes within the section that is not described in the learning outcomes document.
Students are not yet familiar with process safety and they do not have preliminary knowledge about process safety coming from other courses within the university. Three participants added that it might be an advantage for them to have some preliminary knowledge about process safety.
At the end of the section participants were asked if a university does not teach process safety, what is the reason? Some gave their view that maybe the lecturers have either not worked in industry, which means that they do not necessarily prioritise process safety to the same level as industry does or it might be due to the lack of competent staff to teach it. Others added, that the problem is originated from the lack of understanding of the similarities and differences between process and personal safety.

Section B

Section B targeted the principles of inherently safer design. Participants asked if they teach Process Safety in Design within the Chemical Engineering course. Majority of the universities have inherently safer design in their curricula but not in the first year.
The next question explored if participants find the topic relevant to the Chemical Engineering course. If not, whether they think it would fit in with a Mechanical Engineering or a Civil Engineering course. Meanwhile all responders find the topic relevant to the Chemical Engineering course, some added that general safety courses may fit as well also in Mechanical Engineering and in Civil Engineering. Industry is interested in extending process safety to Mechanical Engineering or a Civil Engineering course. An additional thought was that other disciplines such as Mechanical and Civil can also benefit from listening or at least have some sense on what this means in practice. In real life, these process design/engineering decisions are done mainly by the process engineers. These decisions, however, have great impacts on mechanical and civil (and other) engineering disciplines as they will have to find the required mechanical equipment, decisions on layout, foundation structures, etc. One university highlighted that, although process safety is most relevant to Chemical Engineering, the concepts such as layers of protection certainly apply to other engineering disciplines where unintentional release of energy with the potential to injure people may occur.
This question led to the discussion on the concept of safety barriers and how much students know about design. Majority said that even though students are fairly familiar with the concept of inherently safer design, they may not know much about safety barriers. The rigour of barriers thought of by students is challenging for them to capture and understand. For example, one university replied that students are aware of the alarms and emergency shutdown systems. These are introduced as safety barriers, specifically recalling the need of redundancy. Other say that engineering disciplines are very complex in nature and require strong collaborations between disciplines. Due to its complexity, sometimes teachers as the process engineers, miss some trivial safety design issues, which can be easily spotted and corrected by the other disciplines. In their case, the course is introduced in the final year. Hence, it is very relevant in a way that at the same time, students have the plant design project, which they can implement the overall knowledge of inherently safer design, especially that students have done eight months’ internships. This participant does not think that introducing this in earlier year would benefit them. Another participant responded similar, that senior students learn the fundamentals of barriers. The course includes safety in design principles such as inherently safer design and failure modes of unit operations.
Another university does introduce the concepts of risk assessment and barriers in the first year and builds upon the knowledge in the second and third years from initially simpler problems to more complex scenarios and also gives students the opportunity to apply their learnings on risk assessment exercises. They have found this approach to work well.

The last question tackled the different codes, regulations and students' knowledge on those. All participants replied that they teach the relevant industry codes, standards, the regulations and directives in force, such as COMAH, SEVESO or ATEX. Students are given an awareness of design codes, standard based design and regulations. However, due to intellectual property issues, accessing codes and tailoring examples where codes can be applied there are issues in how rigorously this can be taught and there is limited opportunity to apply these learnings.

Section C

Section C focused on process safety risk assessment and participants had to answer to the question if they teach Process Safety Risk Assessment (RA) within the Chemical Engineering course. All responders said yes to this question and they added that RA is taught in the form of hazards identification, HAZOP (interactive workshops, and assignments) and LOPA (general overview). More can be done but since these concepts are introduced from the first year and revisited or applied at different stages throughout the degree programme then this is already a significant step in the right direction. Another participant said that RA is included in the Process Safety and Loss Prevention course. The Crowl and Louvar's Chemical process safety: fundamentals with applications is used as the textbook (Crowl and Louvar, 1990). The students are exposed to the quantitative risk assessment (QRA) procedure and application of common software used by industries such as SAFETI by DNV GL. They are required to conduct a simple QRA for selected case studies from several plants using the fundamental theory that they have learned and through application of the QRA software.

One participant stated that both Hazard Identification and Analysis, both qualitative and quantitative methods together with RA are included in the curriculum of the dedicated course.

Meanwhile, another university replied that students are required to attend a three hours Risk Management course that covers the importance of risk management, awareness of different types of hazards in the workplace and finally, they gain knowledge how to complete a RA.

Some indicated time constraint to address this specific topic in an extended form/way.

3. Conclusions

The benchmarking exercise gave the opportunity to universities to give feedback about how the Learning outcomes may function in either Chemical Engineering courses or other disciplines. It is very promising that all participants teach process safety either in the form of single or integrated course. As some of them addressed in the responses, students are not yet familiar with process safety and they do not have preliminary knowledge about process safety coming from other courses within the university. It might be an advantage for students to have some preliminary knowledge about process safety. According to some participants, universities may not teach process safety because the lecturers may not have worked in industry, which means that they do not necessarily prioritise process safety to the same level as industry does or it might be due to the lack of competent staff to teach it. The problem can also be originated from the lack of understanding of the similarities and differences between process and personal safety which should be addressed in these programs.

Meanwhile all responders found the topic of inherently safer design relevant to the Chemical Engineering course, some believe that general safety courses may fit as well also in Mechanical Engineering and in Civil Engineering. Further to that, both Mechanical and Civil Engineering can benefit from listening to what inherently safer design means in practice. Even though students are familiar with the concept of inherently safer design, they may not know much about safety barriers; it is challenging for them to capture and understand. However, as participants highlighted, this topic is crucial in real life.

Risk assessment and hazard identification are those topics that are taught in all participating universities. Some use commercial software tools and all get familiar with the concept of risk assessment, even LOPA or the concept of ALARP. Some addressed that more can be done in this topic but since these concepts are introduced from the first year, and revisited or applied at different stages throughout the degree programme then this is already a significant step in the right direction.

Based on their response, universities are up to date about the relevant laws and standards applied across industry; students are given an awareness of design codes, standard based design and regulations. However, due to intellectual property issues, accessing codes and tailoring examples where codes can be applied there are issues in how rigorously this can be taught and there is limited opportunity to apply these learnings.

A final note; at least three universities have adapted the ISC interactive case studies to gain other additional insights and support learning outcomes of introductory safety courses given to either second or final year undergraduates. A paper on application of case study material in undergraduate learning by Kerin and Pollock

(Kerin and Pollock, 2018) will be published soon and it discusses the potential in the application of the interactive case studies.

Acknowledgments

The author would like to acknowledge the contributions made to the benchmarking exercise by the following universities:

- Department of Civil, Chemical, Environmental and Materials Engineering University of Bologna
- Department of Chemical & Process Engineering University of Strathclyde
- Department of Chemical Engineering Michigan Technological University
- Department of Chemical Sciences University of Limerick
- School of Chemical Engineering and Analytical Science, University of Manchester
- Department of Chemical Engineering University College London
- Department of Chemical Engineering Monash University
- RMIT University Chemical Engineering
- Chemical Engineering Department Universiti Teknologi PETRONAS

References

IChemE Safety Centre (ISC, 2018), 2018, Learning Outcomes, Improve Process Safety Education in Undergraduate Engineering, IChemE.

IChemE Safety Centre (ISC, 2014), 2014, Process Safety and the ISC – a framework, IChemE.

Directive 2012/18/EU of the European Parliament and of the Council of 4 July 2012 on the control of major-accident hazards involving dangerous substances

Control of Major Accident Hazards Regulations, (COMAH, 2015), 2015

UK Health and Safety Executive (HSE, 2001), 2001, Reducing Risk, Protecting People, Health and Safety Executive. ISBN 0 7176 2151 0

CROWL, D. A., & LOUVAR, J. F. (Crowl and Louvar,1990), 1990, Chemical process safety: fundamentals with applications. Englewood Cliffs, N.J., Prentice Hall.

Trish C. Kerin, Michaela Pollock (Kerin and Pollock, 2018), 2018, Application of case study material in undergraduate learning