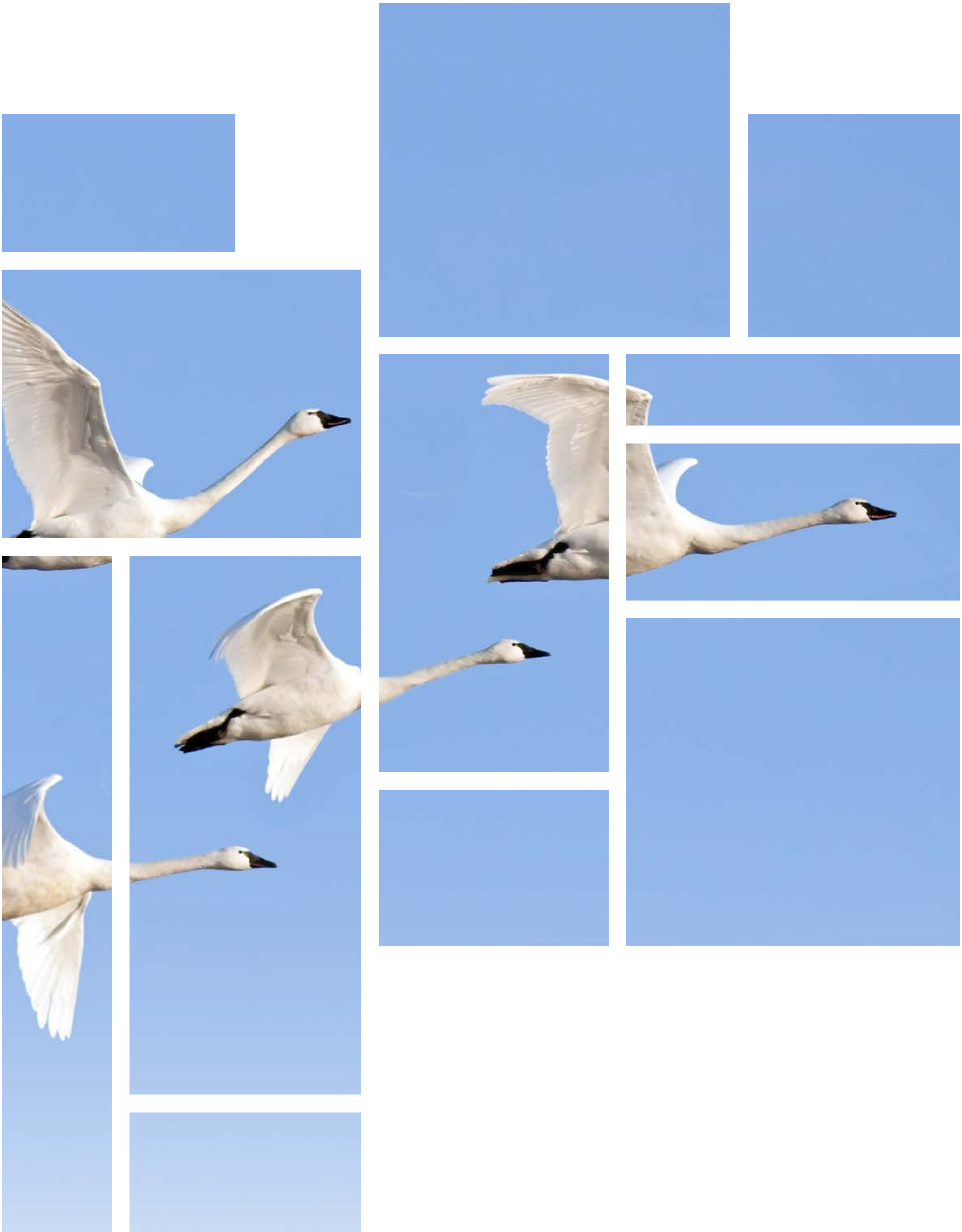
IChemE ADVANCING CHEMICAL ENGINEERING WORLDWIDE

Learning Outcomes

Improve Process Safety Education in Undergraduate Engineering

Edition 1, 2018

IChemE Safety Centre



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Preface

The IChemE Safety Centre (ISC) is an industry-funded and led organisation, focussed on improving process safety through sharing information and learnings. ISC member companies can nominate specific areas of focus, and ISC leads the development work in these areas. Undergraduate process safety education was identified as a project, and defined by the ISC Advisory Board and the project sponsor.

The project aimed to determine industry's expectations on process safety education at undergraduate level, and initially present them to a range of universities at Chemeca 2016, before sharing more widely with other universities around the world. That consultation has resulted in this document, which covers industry's expectations and highlights some information and resources that universities can use to meet them.

This document does not seek to mandate how process safety should be taught nor what curricula should contain. Its contents are not accreditation guidelines, but provide guidance on industry expectations and resources available or being developed. While the learning outcomes are based on a typical 4-year chemical engineering undergraduate course, it is acknowledged that the full list of learning outcomes may not be achievable on all undergraduate courses.

This document supports the ISC functional approach to process safety. Process safety is about managing the integrity of operating systems by applying inherently safer design principles, engineering and disciplined operating practices. It deals with the prevention and mitigation of incidents that have the potential for a loss of control of a hazardous material or energy. Such loss of control may lead to severe consequences with fire, explosion and/or toxic effects, and may ultimately result in loss of life, serious injury, extensive property damage, environmental impact, and lost production with associated financial and reputational impacts. This framework states that effective management of process safety requires leadership across six functional elements in an organisation. These are:

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

These elements can be thought of as a chain of safety. This is because we do not need failures in all elements to have an incident, but rather multiple failures in one element could result in an incident. The integrity of the chain is in the multiple layers behind it, hence demonstrated knowledge and competency in all elements is required across an organisation. The elements in the chain of safety are often implemented through an organisation's (process) safety management system.

Lastly, this is a living document and we expect that the undergraduate education will evolve over time. If you are involved in undergraduate education, we welcome your feedback on how you are achieving process safety outcomes.

Acknowledgements

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Learning outcomes

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. 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.

The learning outcomes are structured assuming that process safety is delivered as a single subject. However, some or all of the learning outcomes could be integrated into other subjects.

A. Process safety overview

A1	Define the main concepts of process safety and describe the benefits of process safety to an organisation 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.

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.

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; and • 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.

D. Process safety in practice

In addition to classroom learning, there are opportunities to review how process safety is applied as part of the wider chemical engineering curricula, including laboratory activities, design projects and industrial training placements. Process safety within industry is usually implemented through a (process) safety management system. Education in Management Systems is best undertaken by industry in an operational environment rather than through university, but the intent of this section is to suggest how undergraduates can get exposure to the type of systems that they will later experience within industry.

The following learning outcomes and associated guides can be used to further apply process safety learning.

D1	Apply, adapt and/or create process safety management system (SMS) elements as part of laboratory, practical or pilot plant activities. Refer to undergraduate laboratory SMS guide below.
D2	Research, investigate and summarise the application of process safety management system elements as part of industrial training placements. Refer to undergraduate industry passport guide below.
D3	Apply regulations, standards, risk assessment techniques, inherent safety techniques and risk-based decisions during design projects. Refer to process safety in design projects guide below.
D4	Identify and evaluate causal factors in process safety incident case studies. Refer to process safety case studies guide below.

Learning guides

D1 Undergraduate laboratory safety management system

Learning outcome: D1 Apply, adapt and/or create process safety management system elements as part of laboratory, practical or pilot plant activities.

Laboratory work undertaken at university is normally controlled by a safety management system that includes induction and training, operating and maintenance procedures, risk assessments, etc. As a university laboratory shares some similarities with an industrial application, there is potential for students to appreciate the intent and application of industry process safety management systems by adapting, or developing, and applying a simple university laboratory safety management system, with particular focus on the process safety elements.

An undergraduate laboratory safety management system could include requirements that relate to experimental practice, such as writing of procedures for conducting experiments, identification of the hazards involved in an experiment, evaluation of risk, determination of the required process safety procedures, use of protective equipment, application of basic safe systems of work, and management of change to control variations in experimental parameters and the effects thereof.

The following guide suggests some ways that an undergraduate laboratory SMS can be used as an activity for process safety learning outcomes. Where three levels are shown, this can be delivered through step-by-step gradual skill-building.

Further material to assist in implementing a laboratory safety management system will be available from the ISC.

	Process safety management element	Possible laboratory process safety activities
D1.1	Hazard identification and risk assessment	Level 1. Read, understand and be familiar with existing risk assessments including recognising why a particular risk assessment technique is used Level 2. Update an existing risk assessment Level 3. Create a hazard identification and risk assessment for a simple and then more complex lab task, eg safe disposal methods for hazardous materials
D1.2	Operating manuals and procedures	Level 1. Apply existing operating procedures for commonly used equipment Level 2. Adapt and modify existing procedures Level 3. Develop procedures for complex lab tasks
D1.3	Operational status monitoring and handover	Perform a formal handover within laboratory teams during complex experimental work or pilot plant operation
D1.4	Operational readiness and process start-up	Level 1. Apply existing procedures for experimental work or pilot plant start-up Level 2. Apply operational readiness checks before commencing experimental work or pilot plant operation Level 3. Describe/develop procedures for experimental work or pilot plant start-up
D1.5	Emergency preparedness	Level 1. Awareness in emergency preparedness and evacuation requirements as part of lab safety awareness training. Level 2. Apply existing shutdown procedures for experimental or pilot plant equipment Level 3. Describe/develop emergency shutdown procedures
D1.6	Inspection and maintenance	Confirm that inspections and maintenance tasks are up to date before using experimental or pilot plant equipment
D1.7	Safe systems of work (eg permit to work)	Perform a Permit-to-Work procedure prior to undertaking experimental work or pilot plant operation
D1.8	Incident reporting and investigation	Level 1. Identify incident reporting processes from laboratory safety awareness training package Level 2. Research typical incidents applicable to laboratory work and describe causal factors Level 3. Write an incident report for a typical laboratory process safety incident and undertake a simple incident investigation

D2 Undergraduate industry passport

Learning outcome: D2 Research, investigate and summarise the application of process safety management system elements as part of industry placements

As part of industry placements and site visits, chemical engineering undergraduates will be exposed to safety management systems in practice, including induction, training, procedures and risk assessments. This provides an opportunity for the university and company to provide an environment where the undergraduate can utilise the placement to further investigate the relevant elements of a process safety management system, such as how the company manages process safety, the different techniques used in the identification of hazards and evaluation of risk, managing change and application of basic safe systems of work.

The following guide can be used to extend the core learning outcomes through the industrial placement and to record an undergraduate's exposure to the various elements of a process safety management system and provide an opportunity for further learning through investigation or assignments during the placement.

Exposure to different process safety management elements will depend on whether the industrial placement is in operations, design projects, corporate office, etc and the possible learning outcomes available from the placement will vary accordingly.

Further material will be available from ISC, including an "industry passport", to allow undergraduates to record their exposure to safety management systems in practice.

	Possible undergraduate industry placement learning outcomes	What to look for during industrial placements
D2.1	Investigate how the organisation benefits from process safety and how the organisation differentiates between process and personal safety.	• A health, safety and environment or process safety policy signed by senior management that demonstrates commitment to process safety • Discuss the differences between process safety and personal safety with personnel • Visual displays (eg on notice boards) demonstrating the difference in personal safety and process safety reporting
D2.2	Investigate and evaluate the Process Safety Management System elements implemented within the organisation.	• A documented health, safety and environment or process safety management system in use • Formal management of change reviews undertaken for equipment, systems or organisational changes • Permit-to-Work activities undertaken on process equipment • Incident investigation reports • Safety alerts showing lessons from incidents • Organisational learning system • Audit reports • Action tracking system • Emergency response plans • Emergency evacuation drills • Operational and work procedures in use
D2.3	Compare the advantages and disadvantages of risk-based design versus code/standard-based design in the overall PSM framework (if industry placement within a design environment)	• Applicable safety legislation (eg ALARP/SFARP) and industry standards • Design standards and procedures describing process safety

	Possible undergraduate industry placement learning outcomes	What to look for during industrial placements
D2.4	Determine the main process hazard analysis tools used in the organisation and compare their uses, benefits and limitations. Undertake appropriate hazard identification/risk assessment studies and evaluate their effectiveness.	• Documented hazard identification and risk assessment procedures for process safety • Review risk assessments undertaken (eg QRA, LOPA in safety case formal safety assessments) • Participate in hazard identification or risk assessment (e.g. HAZOP, HAZID, bow tie) workshops
D2.5	Determine how barrier effectiveness is assessed and investigate the role of critical activities like monitoring, inspection and maintenance in barrier effectiveness.	• Documented performance standards for safety critical equipment • Maintenance and inspection plans and records for safety critical equipment • How testing frequency for safety systems is determined • How the effects of human factors on barrier effectiveness are assessed

D3 Process safety in design projects

Learning outcome: D3 Develop and apply process safety standards and regulations, risk assessments, inherent safety techniques and risk-based decisions during design projects.

The following table indicates possible activities that could be undertaken during undergraduate design projects to extend the learning outcomes.

	Possible process safety in design projects learning outcomes	Design project activities
D3.1	Define the concepts of inherent safety and list typical approaches to inherently safer process design.	• Identify inherently-safer design options during process selection phase of design project
D3.2	Describe the benefits of multiple barriers and list typical barrier types for various process excursions.	• Identify typical layers of protection (barriers) for process excursions associated with the selected process design
D3.3	Compare the advantages and disadvantages of risk-based design versus code/standard-based design in the overall PSM framework.	• Identify the applicable regulations and industry standards and consider hierarchy of regulations and standards (mandatory vs recommended)
D3.4	Identify various process 'hazards' and develop 'risk' phrases in terms of loss of control of hazards. Include identification of: • process hazards • the potential consequences of a failure to keep them contained/controlled • threats to containment of hazards • prevention and mitigation controls	• Identify incidents and lessons learned from similar designs and incorporate into risk assessments and design process • Consider human factors and human error as a potential cause of process incidents

	Possible process safety in design projects learning outcomes	Design project activities
D3.5	Define the main concepts of common process hazard analysis tools. Describe qualitative and quantitative risk assessment techniques, their uses, benefits and limitations. Perform a hazard identification/ risk assessment study on a process safety scenario.	• Determine the appropriate hazard identification and risk assessment techniques to be used at different project stages • Maintain a risk register as part of the design project • Undertake a HAZID (or preliminary hazard assessment) early in the design project • Undertake a detailed HAZOP and LOPA • Perform quantitative assessment of risks using fault and event trees, risk contour plots, etc
D3.6	Describe the concepts of As Low As Reasonably Practicable or/So Far As is Reasonably Practicable and undertake the steps required to demonstrate that a risk has been reduced ALARP/SFARP (depending on jurisdiction).	• Compare design options and analyse risks to demonstrate that risks associated with the chosen design have been reduced so far as is reasonably practicable • Document how the hierarchy of controls model has been used to consider and/or reject controls in order to demonstrate ALARP/SFARP

D4 Process safety case studies

Learning outcome: D4 Identify and evaluate causal factors in process safety incident case studies.

Case studies can be used to reinforce and extend process safety learning outcomes as part of the undergraduate chemical engineering course syllabus.

When considering a case study as part of the syllabus, there are two components of the case study that contributes to the learning outcomes:

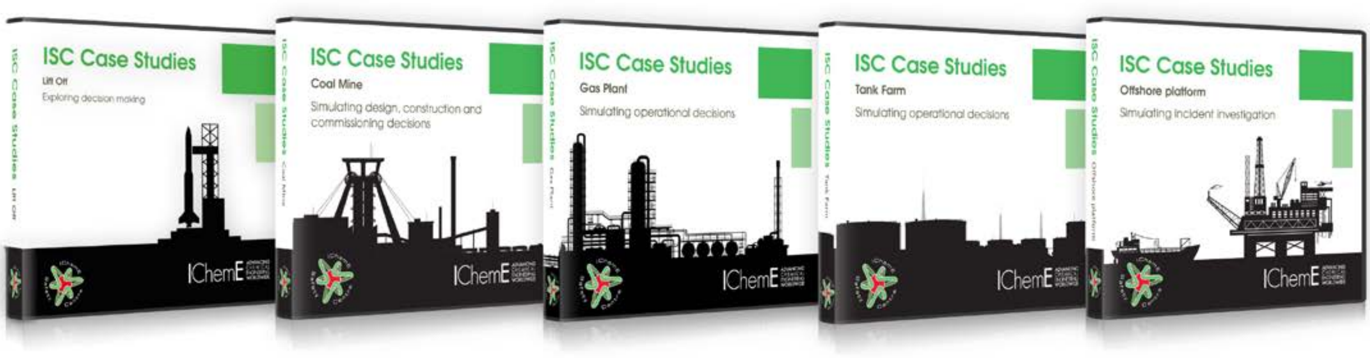
1. The topics covered by the case study, for example process safety in design, risk assessments, Permit-to-Work systems and incident investigations. This affects the topic of the learning outcome.
2. The method, media and tools used in delivering the case study. This affects the level of learning that may be achieved.

The following learning outcomes can be developed from various case studies dependent on content and delivery method.

There are a range of resources available on case studies. The United States Chemical Safety and Hazard Investigation Board (CSB) and ISC have a range to choose from in different formats.

The Institution of Chemical Engineers (IChemE) also publishes the *Loss Prevention Bulletin* (*LPB*) with a range of different case studies.

	Possible process safety case study learning outcomes
D4.1	Describe how process safety concepts and the difference between process safety and personal safety is demonstrated through case studies.
D4.2	Give examples of how process safety management system elements failed and contributed to incidents from case studies.
D4.3	Analyse case studies and describe how multiple barriers are used to provide layers of protection. Explain how barrier failure could have been prevented in the case study examples.
D4.4	Describe how different risk assessments were utilised in the case studies and evaluate whether they were applied effectively.
D4.5	Critically evaluate the process safety causal factors relating to the case studies and demonstrate how the causal factors reflect back on the process safety syllabus.



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