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# A process safety framework for teaching and learning

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# Work in Progress: A Process Safety Framework for Teaching and Learning

**Abstract**
Incidents such as Bhopal, T2 and the 2020 Beirut explosion have continued to remind chemical engineers of the personal, environmental and business cost of not designing with process safety in mind. Industry uses a framework to help engineers design and evaluate processes. This same process safety framework is used in CCPS/Industry process safety faculty workshops to teach faculty about process safety. The framework and associated learning outcomes can help departments define and assess program goals for process safety, enable faculty to integrate content into their existing courses and help faculty design new process safety courses. Teaching students to use the framework helps them to organize information learned and identifies areas for improvement. This work-in-progress presentation will show how this framework is grounded in pedagogical theory and can be used for all these applications. Furthermore, the framework is being used to design the 5th Edition of Chemical Process Safety: Fundamentals with Applications to support teaching and learning.

## Introduction

Incidents such as Bhopal, T2 and the 2020 Beirut explosion have continued to remind engineers of the personal, environmental and business cost of not designing and operating with process safety in mind. Therefore, process safety education is imperative to help reduce the frequency and consequences of incidents. A textbook is one tool educators can use to teach learners about process safety and it should be designed with effective pedagogy in mind. The Chemical Process Safety: Fundamentals with Applications 5$^{th}$ Edition textbook will be redesigned using researched based pedagogical theories.

## Pedagogical Theories

Pedagogical theories provide educators with frameworks for effective teaching and learning. Three theories that have demonstrated effective learning are constructivist pedagogy (CP), inquiry-based learning (IBL) and problem-based learning (PBL).

Constructivist pedagogy uses authentic real-world situations to demonstrate how theory and skills are put into practice.[1] It focuses on modeling problem solving, and scaffolded learning to guide the learner from what they know to what they don't know. [2, 3] This theory highlights the value of taking multiple perspectives, which is important for solving today's complex societal problems. This theory also highlights the importance of using assessments that are context driven in order to measure learning. [4, 5]

Similar to the constructivist pedagogy is inquiry-based learning. IBL also uses authentic problem-based questions and highlights the importance of guided inquiry. The focus of inquiry-based learning is to learn through asking questions. This method encourages learners to question first and begin problem solving through curiosity.[6]

Problem based learning is another pedagogical theory that focuses on developing problem-solving skills, a key skill for engineers. This theory highlights the importance of knowledge frameworks. A knowledge framework is a structured method to identify, analyze, and solve novel complex problems. [7] Knowledge frameworks are important because they connect pieces

of information together within the context of the bigger picture in which the problem resides. Experts use knowledge frameworks to take information and apply prior knowledge to a new but similar situation to solve new problems.

Given these effective learning theories, the question becomes, how can they be utilized to create a textbook tool that educators can use to teach process safety? The constructivist pedagogy highlights the importance of moving a learner from what they know to what they don't know and then help the learner understand the importance of what they are learning and how it is applied in the real-world. [8]. Problem based learning highlights the importance of creating a framework to show how information is connected. This helps learners understand what they are learning and why they are learning it before diving into the more detailed and theoretical aspects of the subject area. Inquiry based learning emphasizes the importance of learning by asking questions.

**Current Textbook Designs**

A textbook is a useful tool for educators because it can contain the majority of information to be taught in a single resource for learners. Textbook also enable learners to preview and reflect on information that is taught in the classroom. Textbooks further have example problems and exercises that enable learners to put knowledge and skills into practice. Challenges associated with textbooks include [8]:

- The information must be organized to move from what the learner knows to what they don't know.
- References must be provided for further study.
- The learner should understand how the information in each chapter is connected.
- The information should show how it is applied in real world contexts.
- Textbooks should encourage inquiry-based learning.

A 2023 survey of 95 institutions in the US and Canada, looked at how process safety is taught. The survey included 52 faculty that taught process safety at ABET accredited universities. Of the institutions that reported that their department required a process safety course and used a textbook (N=32), 89% of courses used Chemical Process Safety: Fundamentals with Applications by Crowl and Louvar and 26% used Process Safety for Engineers by AIChE CCPS. Other process safety textbooks identified that were not mentioned in the survey include: Process Safety Calculations by Benintendi, Hazards and Safety in Process Industries Case Studies by Purkait, Mondal, Changmai, Volli, and Shu, and Chemical Process Safety Learning from Case Histories, 4th Edition by Sanders. Among all these textbooks there seems to be two main types. One type focuses on applying chemical engineering fundamentals to the practice of process safety (Crowl and Louvar and Benintendi) and the other type focuses on case studies, discussing the strengths and weaknesses of processes in practice (CCPS, Purkait et al, and Sanders).

In the same 2023 survey, faculty teaching process safety identified some general and specific challenges for pedagogical and curriculum development [9]:

- Learners don't know what they don't know.

- The body of knowledge is broad, deep and expanding.
- The information needs to be contextualized in real world practice and case studies are needed.
- A real-world example with a piping and instrumentation diagram (P&ID) is needed.
- Process safety is applied to a variety of industries, more examples beyond the petrochemical industry are needed.
- There is confusion between personal safety, lab safety, and process safety.

Using this information along with effective pedagogical theories, process safety textbooks should be redesigned.

**Designing with a Knowledge Framework**

In order to organize and enhance learning by connecting information and encouraging inquiry, the Chemical Process Safety: Fundamentals with Applications 5th Edition textbook will be organized using a knowledge framework (PBL) and the framework will be comprised of six questions (IBL). The framework is currently used by industry experts to design and evaluate processes.[10] This same process safety framework is used in CCPS/Industry process safety faculty workshops to teach faculty about process safety.[11] Teaching learners to use the framework will help them to organize information learned, connect ideas, and identify areas for learning growth. The process safety framework also has the potential to help departments define goals for process safety by identifying which questions are addressed in their curriculum. The framework also enables faculty to integrate content into their existing courses simply by asking the questions. The framework can help faculty design new process safety courses by helping them identify what they are teaching and what they are missing.

The Process Safety knowledge framework is composed of six key questions:

1. What are the hazards and how are they characterized?
2. How can the hazards be eliminated or controlled?
3. What can go wrong and how?
4. What are the consequences?
5. What is the likelihood?
6. What is the risk and is it acceptable?

The framework is intentionally composed of questions to encourage inquiry-based learning. The field of process safety is not static. Forming the framework as questions encourages learners to keep learning as knowledge and technology in the field evolve. The added benefit of this framework is that it can be applied not only to process safety, but to personal safety, lab safety, pilot plants, and anywhere else hazards exist. The answers may be different, but the framework stays the same, allowing for effective evaluation in all situations. These questions can be used by novices and experts alike in the work environment to evaluate the safety of a process.

**The Real-World Application of Process Safety**

In order to connect learning to real world practice (CP), literature case studies will be presented. These case studies will be drawn from incidents and best practices in different industry sectors including energy, environmental, food and agriculture, pharmaceutical and biotechnology, personal care, mineral, and specialty chemical. These incidents and best

practices will highlight the impact that process safety can have on people, the environment and the business. Examples will include, Union Carbide Bhopal Disaster (chemical), Alcoa (mineral), Imperial Sugar Dust Explosion (food), West Pharmaceutical Explosion (pharma), Texas City Disaster (agriculture), Fukishima Nuclear Power Plant Explosion (energy), carbon capture and wastewater treatment (environmental).

Process safety is interdisciplinary in industrial practice. Different roles include scientists, engineers, operators, leaders and management, regulatory and quality control and assurance among many others. It is important to understand how different roles collaborate to create a safe environment. Each chapter in the Chemical Process Safety: Fundamentals with Applications 5th Edition textbook will include a list of different roles, and how these different roles collaborate to answer the framework questions.

**Knowledge and Skills in Process Safety**

For each framework question, knowledge, application and design content will be given (CP). Within the Chemical Process Safety: Fundamentals with Applications 5th Edition textbook, key vocabulary will be defined to grow knowledge, and links to reference material will be supplied. Fundamental engineering principles will be connected to the framework questions to show how transport, kinetic, and thermodynamic models are applied in the field of process safety. In chapter examples and homework problems grounded in real world application will be provided to encourage student practice of knowledge and skills. These applications will include energy, environmental, food and agriculture, pharmaceutical and biotechnology, personal care, and specialty chemical.

Each framework question will be applied to a real-world multi-purpose 100-gallon vessel system. This process is chosen because it is relevant to many different process industries. A piping and instrumentation diagram (P&ID) and equipment specifications for the system will be included to meet the faculty's need for an authentic example. The system is designed to operate as a batch, semi-batch or a continuous process. This system will be used repeatedly throughout the textbook to illustrate how designs and specifications change to meet the industrial need based on the hazards in the process.

**Effective Teaching and Learning**

Designing this Chemical Process Safety: Fundamentals with Applications 5th Edition textbook using pedagogical theories, should provide educators and learners a framework for learning, encourage inquiry-based learning, connect to real-world applications, and enhance learning for everyone. The textbook is designed for flexible teaching. The beginning of the textbook will include the overall framework and use case studies to illustrate the framework in process safety practice. The first few chapters alone can be used to develop a short course and is suitable for engineering and non-engineering learners. Subsequent chapters can be used in a wide variety of formats. This could include designing a full-semester or graduate level course or just adding content to other core engineering courses. Instructors can focus on one framework question or choose a process or hazard and answer the framework questions for that particular process/hazard. The new design will enable educators to use the book flexibly to meet their desired learning outcomes.

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