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Continuous Improvement in Process Safety Education

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The importance of continuous improvement is emphasized in this paper from the perspectives of process safety education in general and university process safety courses in particular. Feedback on concept familiarity from undergraduate and graduate students was used to adjust the learning outcomes developed for one such course. In this manner, the *plan/do/check/act* protocol utilized in industrial process safety management systems was applied to academia. The paper concludes with a brief examination of other means of continuous improvement, including forward visioning exercises and learning outcome/competency guidelines produced by technical organizations.

1. Introduction

Formal education of engineering students in the fundamentals of process safety is critical to the continued success of the process industries. Process safety education should therefore be subject to the same *plan/do/check/act* cycle of continuous improvement that is an underpinning feature of a process safety management system (Amyotte and Lupien, 2017). A process safety course itself must be subject to the same scientific rigour as other system-related courses such as reaction engineering and process control. The message imparted to engineering students needs to convey the understanding that process safety is an integral part of engineering education – one that will be used at all stages of a process system lifecycle from conceptual design to decommissioning.
Within the broad scope of process safety education, and motivated by the concerns expressed in the above paragraph, the specific objective of the current paper is to suggest ways to ensure the relevance of process safety course offerings to industrial practice.

2. Process Safety Education

In their recent comprehensive literature review, Mkpat et al. (2018) define process safety education as: *the learning of operating disciplines and safety principles through a systematic approach, with a view to preventing major accidents in the process industry*. They further comment that there are three routes to process safety education: (i) university degree programs at the undergraduate and graduate levels, (ii) professional activities such as internships, on-the-job training, and continuous professional development, and (iii) training in regulatory agencies and inspectorates. It should be noted that these routes are not mutually exclusive. Many undergraduate engineering programs (including chemical engineering at Dalhousie University) offer alternating study and work terms in a co-operative (co-op) education mode.
The process safety course taught at Dalhousie therefore falls in the first route for process safety education given by Mkpat et al. (2018). Consistent with their definition of process safety education above, and as illustrated in the next section, the course incorporates all of the core concepts identified by Amyotte et al. (2016) for the prevention of major process accidents: (i) the creation of paradigm-enhancing organizations, (ii) inherently safer design, (iii) awareness of the total cost of major accidents, (iv) consideration of the broader societal and cultural aspects of major accidents, (v) process safety culture, (vi) process safety competency, and (vii) dynamic operational risk management. (The term *paradigm-enhancing organizations* refers to entities such as the Center for Chemical Process Safety (CCPS), US Chemical Safety Board (CSB), and Institution of

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Chemical Engineers (IChemE) – among many others. The Dalhousie process safety course relies heavily on educational material produced by these organizations.)

3. Process Safety Course

In this section we describe the origin and evolution of the Dalhousie process safety course (hereafter referred to simply as the course). Each of the stages in the *plan/do/check/act* cycle is considered in turn.

3.1 Process safety course: *plan*

The course taught at Dalhousie has been described in a previous paper (Amyotte, 2013). It is largely structured around learning outcomes designed to meet performance indicators for graduate attributes mandated by the Canadian Engineering Accreditation Board or CEAB (CEAB, 2017). Table 1 gives a listing of the course learning outcomes (with action verbs as recommended by Felder and Brent, 1997) and the corresponding CEAB graduate attributes. Also shown in Table 1 are the corresponding levels in *Bloom's Taxonomy of Educational Objectives* (see, for example, Krathwohl, 2002). Amyotte (2013) describes the other determinants on which the course is based (in addition to the requirements of accreditation bodies): (i) professional practice regulatory bodies, (ii) technical societies, (iii) process safety and related literature, (iv) industrial resources, and (v) features unique to a given institution.

Table 1: Learning outcomes based on Bloom's taxonomy and CEAB graduate attributes (original)

Learning Outcome	Taxonomy	Graduate Attribute
1. Apply a loss causation model to determine root causes of incidents	Apply	Knowledge base for engineering
2. Recommend appropriate safety management system elements to remediate hazards arising in industrial processes	Evaluate	Economics and project management
3. Formulate a hazard identification protocol to assess potential hazards in a given industrial process	Create	Design Use of engineering tools
4. Explain the basics of inherently safer design using both technical and everyday-life examples	Understand	Knowledge base for engineering
5. Analyze and critique several process industry case studies with respect to core concepts such as inherently safer design, process safety management, and fire and explosion risk reduction measures	Analyze Evaluate	Impact of engineering on society and the environment Economics and project management
6. Resolve the issue of conflicting demands of safety and production using process industry case studies drawn from various regions of the world	Evaluate	Impact of engineering on society and the environment

3.2 Process safety course: *do*

The course had been taught with the learning outcomes shown in Table 1 for about five years prior to 2015 (see Section 3.3). Typical assessment vehicles were used for measurement of learning outcomes: course exercises, assignments, tests, and a final exam.

As described by Amyotte (2013), an invaluable resource in delivering the course has been the US Chemical Safety Board and its investigation reports and accompanying videos. A representative set of questions drawn from typical CSB reports, which have been employed to good effect in a team-based take-home scenario in the course, follows (Amyotte, 2013):

- Explain why it is important for engineers to study case histories such as this CSB report.
- Demonstrate how the concepts of safety culture, collective mindfulness, and risk-awareness are relevant to this incident.
- Analyze the causation and propagation of the incident from the perspective of the hierarchy of controls for risk reduction. Among other points you feel are important, you should explicitly consider whether a lack of application of inherent safety principles played a role in the incident, as well as the overall effectiveness of engineered and procedural measures.
- How did Management of Change (MOC) play a role in this incident? In addition to consideration of MOC, what other elements of the Canadian Society for Chemical Engineering version of Process Safety Management (PSM) would have been beneficial in prevention of this incident as well as mitigation of the consequences? Provide full justification for your choices.

- You have taken many other courses in your undergraduate engineering program in addition to the current course on industrial safety. Describe how the material you have studied in two of these other courses is relevant to the CSB report under consideration. Your answer must include specific examples to establish the link between the courses and the incident.
- Perform a complete domino loss causation analysis for this incident.
- Analyze the incident in terms of the complete sequence of prevention, preparedness, response, and recovery (PPRR).
- Explain the role of human error in the causation and propagation of the incident, and discuss the human factor considerations required to prevent similar incidents from occurring.
- Develop a training scheme that could have been implemented prior to the incident to emphasize the particular hazard(s) involved.
- Perform a complete What-If? analysis which, had it been done prior to this incident, might have helped prevent the incident and mitigate its consequences.
- Analyze the incident causation from the perspectives of both the fire triangle and the explosion pentagon.
- In investigating this incident the CSB used a root cause logic diagram. Compare this approach with the domino model for loss causation analysis. Among other points you feel are important, include a description of the similarities and differences between the two methodologies.

3.3 Process safety course: *check*

In the fall term of 2015 there were 75 undergraduate students and 20 graduate students enrolled in the course. The high number of graduate students was due to a need for graduate courses based on a shortfall in a course-based Master's program. Graduate students completed additional assignment work.

The final exam in 2015 contained the following question: *In the first class,* [the statement was made] *that each concept … covered in this course would either: (i) teach you something completely new, (ii) provide the theoretical basis for something with which you already had practical experience, or (iii) affirm and validate your existing knowledge. Identify a course concept that – for you – falls into each of these three categories (different concept for each category).*

Student responses were collated and analyzed according to the following primary course topics:

- Introduction: motivation; definitions
- Loss causation: incident causation models
- Management aspects: safety management systems (PSM); Responsible Care®; safety culture
- Legislative (regulatory) aspects: Nova Scotia Occupational Health & Safety Act; internal responsibility system; due diligence
- Incident investigation: purpose; investigation methodologies
- Hazard identification: inspection; checklist; what-if; what-if/checklist; failure modes and effects; fault tree; event tree; bow-tie
- Safe work practices and procedures: job safety analysis; human error; human factors
- Communication aspects: incident report writing; group dynamics; off-site communication
- Training: needs analysis; program development and monitoring; learning styles
- Inherently safer design: hierarchy of controls; inherent safety; passive engineered safety; active engineered safety; procedural safety
- Fires and explosions: fundamentals; flammability data; hazard evaluation, prevention and mitigation; fire triangle and explosion pentagon; codes and standards
- Risk assessment: likelihood analysis and consequence analysis; relative risk ranking (Dow Fire & Explosion Index and Chemical Exposure Index); risk matrix (in conjunction with HAZOP)
- Case studies: Flixborough; Seveso; Bhopal; Piper Alpha; Westray; others (several incidents investigated by the CSB)

Data analysis is displayed in Figures 1 – 3 (undergraduate student responses, graduate student responses, and combined (undergraduate and graduate) student responses, respectively). Not unexpectedly, there is a strong correlation between specific learning outcomes (Table 1) and their corresponding concepts:

- Loss causation: Learning outcome No. 1
- Role of management: Learning outcome Nos. 2, 5 and 6
- Hazard identification: Learning outcome No. 3
- Inherently safer design: Learning outcome Nos. 4 and 5
- Fires and explosions: Learning outcome No. 5
- Case studies: Learning outcome Nos. 5 and 6

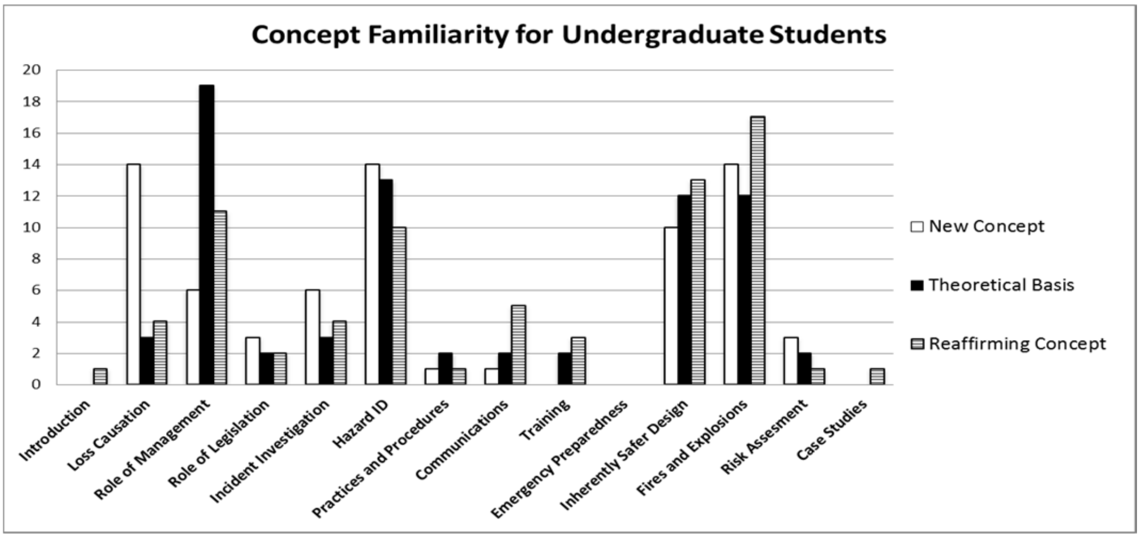

Figure 1: Undergraduate student responses to concept familiarity question

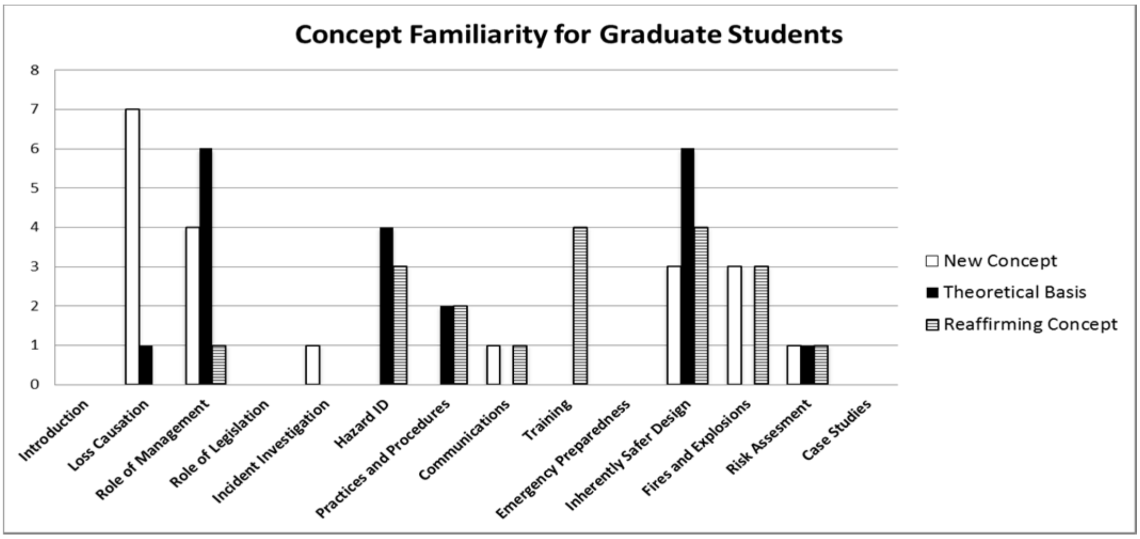

Figure 2: Graduate student responses to concept familiarity question

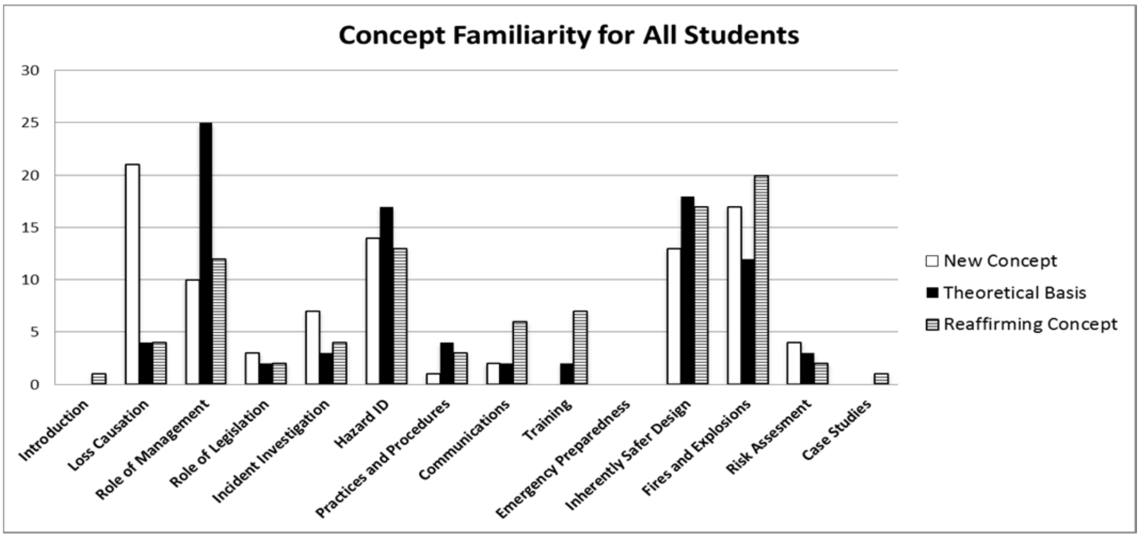

Figure 3: Combined (undergraduate and graduate) student responses to concept familiarity question

3.4 Process safety course: *act*

The data shown in Figures 1 – 3 are highly dependent on the makeup of the class (e.g., previous industrial experience in terms of co-op work terms and longer periods of employment before entering graduate school). The data also represent a limited snapshot in time (i.e., data collection and analysis for only one particular class). Nevertheless, some general trends can be observed, which are helpful in affirming and modifying the original learning outcomes given in Table 1.

For example, *loss causation* was overwhelmingly identified as a new concept by both undergraduate and graduate students who selected this topic. This was taken as evidence of the need to retain the learning outcome related to incident root cause determination (No. 1 in Table 1), while also providing reinforcement in terms of a new learning outcome related to remembering process safety terminology (*loss*, *incident*, *accident*, *hazard*, *risk*, etc.).

Table 2 gives the revised learning outcomes for the course as it is currently being delivered in the fall term of 2018. In addition to the change described in the previous paragraph, the number of learning outcomes has been held at six by incorporating original learning outcome No. 2 (Table 1) more fully into revised learning outcome No. 4 (Table 2). The order of the learning outcomes was also changed in Table 2 to flow from least to most challenging level in Bloom’s taxonomy.

One can see in Figure 1 that *hazard identification* was fairly evenly split among the three categories of concept familiarity for undergraduate students selecting this particular topic. Although no graduate student identified *hazard identification as* a new concept, original learning outcome No. 3 (Table 1) was retained as revised learning outcome No. 6 (Table 2) given that the course is fundamentally designed for undergraduate students.

Table 2: Learning outcomes based on Bloom’s taxonomy and CEAB graduate attributes (revised)

Learning Outcome	Taxonomy	Graduate Attribute
1. Define industry standard terms such as process safety, occupational safety, hazard, risk, inherent safety, and hierarchy of controls	Remember	Knowledge base for engineering
2. Explain the basic principles of inherently safer design using both everyday-life and technical examples	Understand	Knowledge base for engineering
3. Identify root causes of process incidents by means of a loss causation model	Apply	Knowledge base for engineering
4. Critique process industry case studies and recommend alternative risk reduction measures with respect to core concepts such as safety management system elements, inherently safer design and the hierarchy of controls, and fire and explosion safety	Analyze Evaluate	Impact of engineering on society and the environment Economics and project management
5. Appraise the issue of conflicting demands of safety and production using process industry case studies drawn from various regions of the world	Evaluate	Impact of engineering on society and the environment
6. Formulate a hazard identification protocol to assess potential hazards in a given industrial process	Create	Design Use of engineering tools

4. Further Course Refinements

Ongoing work in relation to course improvement is drawing on recent publications of the Mary Kay O’Connor Process Safety Centre (MKOPSC) and the IChemE Safety Centre (ISC) on the topics of: (i) process safety research and education visioning (MKOPSC, 2012; MKOPSC/ISC, 2017), (ii) learning outcomes for process safety undergraduate engineering education (ISC, 2018a), and (iii) a process safety competency model (ISC, 2018b). Opportunities are also being explored to integrate the CCPS *Process Safety Beacon* (e.g., CCPS, 2015) and ISC *Safety Lore* (e.g., ISC, 2018c) into course delivery.

Additionally, extended coverage of topics such as Natech (Natural Hazard Triggering Technological Disasters) events, domino effects, and process security is planned for future years. This will likely necessitate the creation of new course learning outcomes beyond those given in Table 2.

Another new learning outcome being developed is intended to address the CEAB graduate attribute on *Professionalism* – in particular, the performance indicator of identifying and applying relevant discipline statutory requirements and codes. The course already contains explicit references to guidance provided by the Nova Scotia Occupational Health and Safety Act (NS OH&S Act), Canadian Environmental Protection Act

(CEPA), Canadian Standards Association (CSA), US National Fire Protection Association (NFPA), ASTM International, and the like.

5. Conclusions

The present work has demonstrated the usefulness of direct student feedback in refining the learning outcomes developed for a process safety course in an undergraduate engineering program. Querying students about their prior familiarity with key course concepts has led, in our case, to appropriately modified learning outcomes that are directly linked to attributes to be achieved at a level commensurate with the time of graduation. In this regard, student feedback has enhanced the effectiveness of the *check* and *act* stages of the *plan/do/check/act* continuous improvement loop utilized in process safety management systems.
The *plan* and *do* stages can similarly be enhanced by making use of the process safety resources available from various paradigm-enhancing organizations (with the paradigm being the current legitimized state of process safety education, research, and practice). Representative organizations include the Center for Chemical Process Safety, Institution of Chemical Engineers Safety Centre, Mary Kay O'Connor Process Safety Center, and US Chemical Safety Board.

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