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Process Safety Education: A Literature Review

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Abstract

In this article, an extensive literature review has been carried out about process safety education. We drafted a process safety model able to systematize the literature review and investigated scientific papers as well as professional articles and so-called grey literature. The presence of a common background emerged, although possibilities for optimization of university curricula are possible, as well as harmonization within universities in different countries and between universities and industry. More collaboration in the field of process safety education is recommended, thereby also involving government agencies and/or control authorities and inspection bodies. In the light of the prevention of major accidents in the chemical industry, the process safety education topic deserves to receive more attention from all parties involved, that is, academia, industry and authorities.

Keywords: *Process safety, education, literature review, chemical industry*

1. Introduction

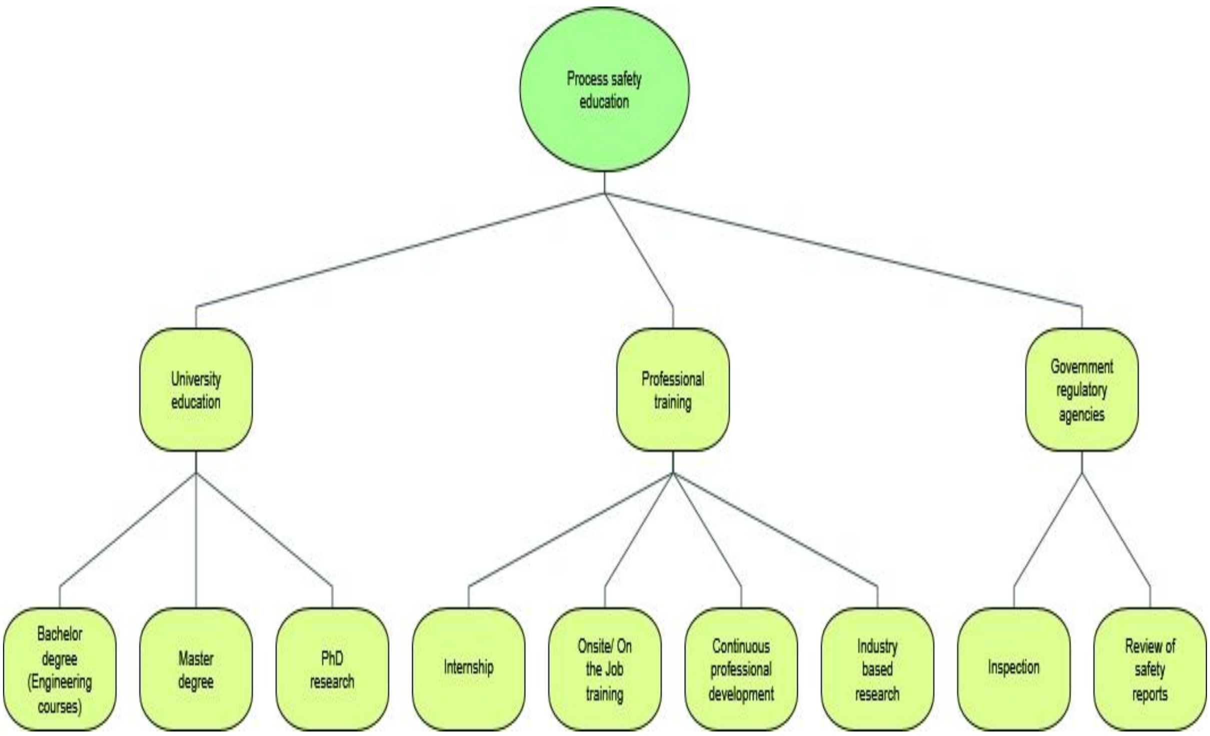
Chemical process installations are increasingly being built and exploited on a large scale, following the rising demands of chemical- related products, which in turn have been driven mostly by globalization, dominant market forces, competitive pressure and economic variables (Hendershot et al., 1999; Mannan 2012; Swuste and Reniers, 2016). In order to meet this demand, these installations often operate continuously, but this can impact both their reliability and performance. However, this can be counteracted through high-level competences of those people operating and managing the installations.

The contribution of process safety education to the daily activities within the chemical process industry (CPI) is significant (Hurme and Rahman 2005; Mannan et al., 2012; Aziz et al., 2014; Hopkins, 2015; Schenk and Antonsson 2015; Majid et al., 2016; Swuste and Reniers, 2016). Process safety education is actually shaped on, and developed due to, major accidents in the CPI. Incidents in this particular industry may have severe consequences for the surrounding environment and for people, as well as for company assets (Khan and Abbasi, 1999; Baybutt, 2016) . The 'process safety related' accidents are characterised with a low frequency of occurrence in combination with high-impact consequences, for instance, multiple fatalities, substantial business interruption, and/or reputation damage (Ditchburn and David, 2006). Such incidents represent a significant license-to-operate risk which can be game-changing for the industry, and detrimental to the society at large.

In the prevention of major accidents, a variety of methods, tools and procedures aimed at the elimination of human and technical design errors, as well as safety management systems are developed; Accident case studies are extensively reviewed and design-based safety and security principles have been developed (Sonnemans & Körvers, 2006; Reniers and Amyotte 2012; Kidam et al., 2014; Leveson and Stephanopoulos 2014). Apart from major accident prevention, process safety education also serves as the basis for process safety knowledge and know-how and the improvement of robust engineering practices in the process industry (Guntzburger et al., 2016).

'Process safety education' refers to the learning of operating disciplines and safety principles through a systematic approach, with a view to preventing major accidents in the process industry. Process safety education is possible through three routes: (i) a university based route, consisting of a bachelor's degree, a master's degree and/ or PhD research; (ii) a professional route, consisting of internships, so-called "On the Job Training" (OJT), Continuous Professional Development (CPD) and/ or industry-based research; and (iii) training in Governmental regulatory agencies (competent for the review of safety reports and for inspections, e.g. in the framework of the application of European Directives addressing the control of major accident hazards). This can be summarized as the 'process safety education model', as illustrated in Figure 1.

Fig.1 Process safety education model



A number of studies with respect to the different parts of the Process safety education model have been carried out. References related to the building blocks of the model can be found in Table 1.

Table 1. Overview of references linked to the Process safety education model

Process Safety Education	Reference
Bachelor degree	Hendershot et al., 1999, Mannan et al., 1999, Osborn 1999, Pintar 1999, Willey 1999, Louvar and Hendershot 2003, Shacham et al., 2006, Ferjencik 2007, Perrin and Laurent 2008, Louvar 2009, Willey et al., 2010, McKay et al., 2011, Crowl 2012, Pasman et al., 2014, Pitt 2012, Saleh and Pendley 2012, Amyotte 2013, Pfeil et al., 2013, Schmidt 2013, Schonbucher et al., 2013, Shallcross 2013, Spicer et al., 2013, Véchot et al., 2014, Dee et al., 2015, Dixon and Kohlbrand 2015, Meyer 2015, Benintendi 2016, Cheah 2016, Krause 2016
Master's degree	Mannan et al., 1999, Lundin and Jönsson 2002, Ferjencik 2007, Perrin and Laurent 2008, McKay et al., 2011, Degreve and Berghmans 2012, Pitt 2012, Schmidt 2013, Schonbucher et al., 2013, Shallcross 2013, Dee et al., 2015, Meyer 2015, Benintendi 2016, Krause 2016
PhD research	Mannan et al., 1999, Perrin and Laurent 2008, Pitt 2012, Meyer 2015, Krause 2016
Internship/ industrial attachment	Ferjencik, 2007, Perrin and Laurent 2008, Pit 2012, Wu et al., 2012, Schmidt 2013, Krause 2016
Continuing education/ on the job training	King 1990, Eckhoff 1994, Cusimano 1995, Lees 1996, Moon et al. 1998, Hub 1999, Mannan et al., 1999, Willey 1999, Cann 2001, Crowl and Louvar 2002, Shacham et al. 2006, CCPS 2007, Hendershot and Smades 2007, Louvar and Hendershot 2007, Louvar 2008, Myers et al., 2008, Sutton 2008, Wasileski, 2009, Haesle et al., 2009, Pasman et al.2014, Pitt 2012, Amyotte 2013, Schmidt 2013, Spicer et al. 2013, Nesheim and Gressgård 2014, Dee et al. 2015, Meyer 2015, Nazir and Manca 2015, Krause 2016
Continuous Professional Development (CPD)	Amyotte 2013, Spicer et al. 2013, Dee et al. 2015, Mannan et al. 2015, Rae 2016, Exida 2017, IChemE 2017
Industry research	Schmidt 2013
Seveso inspection	HSE 2011, HSE 2012, HSE 2015, Sol et al., 2015

In a university setting, process safety education usually begins with a bachelor's degree program or with a module which is embedded into undergraduate engineering programs such as chemical engineering (Hendershot et al., 1999; Krause, 2016). Bachelor's programs including process safety courses introduce students to basic process safety principles and fundamental concepts and take between three and four years to complete. A few bachelors specifically addressing safety engineering were also proposed by several universities (e.g. in Italy the universities of Pisa and of Roma La Sapienza), aiming at forming a technical specialist trained e.g. for the technical corps of emergency responders. In such initiatives process safety is only one of the topics addressed, together with safety instructions about several other engineering disciplines (e.g. nuclear, mechanical, etc.).

The process safety subject can be studied further at master's level, developing student skills and in-depth knowledge in the specialized area of process safety. Master programs in the European context are usually completed within two years. In this case usually process safety is offered as a specific course and/ or as a practical activity as part of a Master Program in engineering disciplines (typically chemical engineering). Some universities offer masters addressing safety or fire safety, with process safety as part of the program (e.g. the University of Padua in Italy), or even master programs addressing specifically Process Safety (e.g. the Polytechnic University of Milan in Italy). Finally, a PhD research program may be undertaken as the final phase of a process safety educational program. This is focused on research in the process safety domain, and is usually completed within three or four years.

Professional training is classified as the second phase of process safety education. It is performed within the industry and sometimes referred to as a 'continuous learning' program. Process safety training is categorised into four programs: (i) an internship enhancing student exposure to industrial activities and further stimulating their theoretical knowledge. This can be completed within three months to one year. (ii) On-the-Job-Training which is derived from professional task execution and task-related functional training, including for instance initial training, retraining and mentoring programs (Crowl and Louvar, 2002; Young and Hodges, 2012). (iii) CPD which is obtained from professional licensure, either as part of career capacity development or professional advancement. Some examples are Professional Engineer (P.Eng), Chartered Engineer (C.Eng), Certified Functional Safety Expert (CFSE), Professional Process Safety Engineer (PPSE). (Exida, 2017; IChemE, 2017). (iv) The final phase of process safety training is an industry-based research program, which is based on innovative experimental research and scientific observations within the industry. Professional training for process safety is mentioned to be important by, and/or is provided in some way via, organisations such as Technology ED, Chris Mee Group, Institute of Hazard Prevention, Petroskills, Georgia Tech Professional Education, ABB, ABS Group, CCPS, Cogent Skills, Competency Training, Dekra Insight, Emerson, Energy Institute, Exida, Health and Safety Laboratory, IChemE, ioMosaic, PrimaTech, Process Improvement Institute, Red Vector, Risknowlogy, TUV Rheinland.

The final route towards process safety engineering education is through inspection. Aside from the implementation of Seveso directives in the European process industry, these inspections also monitor the implementation of Classification, Labelling and Packaging (CLP) of chemical substances and mixtures in Europe (Swuste and Reniers, 2016). Seveso inspectors are themselves subject to OJT, and hence they are classified as being part of the professional training category (Table 1).

Process safety education essentially constitutes life-long learning, as it promotes continuous professional advancement. Its aims to include amongst others an increased understanding of process safety principles, advancement of technical proficiency, and promotion of knowledge sharing (Louvar & Hendershot, 2007; Pitt, 2012; Nesheim and Gressgård 2014). Apart from improving organizational performance, process safety education also promotes several domains of safety culture (see Vierendeels et al., 2018) in an indirect way, and it increases productivity, sustains industry reliability, and enhances sustainable development in the process industry (Cox & Tart, 1991; Elangovan et al., 2005; Sutton, 2008; Myers et al., 2008; Amyotte, 2013; Kluge et al., 2014). Furthermore, Olewski et al. (2016) provide examples and discuss building a process safety culture through and during research.

The main goal of process safety education is to equip employees with the competences for safe and efficient operational conduct within the CPI. The term ‘competency’ refers to professional capability, skills, and experience obtained through structured process safety education and training, in which employees’ task performance is guided by an operational discipline. This concept encourages workers to perform tasks in a safe and efficient manner.

2. Research question and methodology

The aim of this paper is to analyse and explicate the current state of research on process safety education, through a systematic review of existing literature, and to identify possible opportunities for further investigation. This review article is guided by the following research questions.

- What should be taught in process safety education?
- When and how should it be taught?
- How should it be tested and examined?
- When is process safety education efficient?

The material for this research was extracted from both scientific and professional literature. The scientific literature was obtained through a web search using Google Scholar, Science Direct, and Web of Science (WOS) with key words such as *process safety education* and *process safety training*. The below listed scientific journals were extensively utilised for this literature review.

Table 2. List of Journals with corresponding review articles (January 2017 – April 2017)

S/No.	Name of Journal	No. of Articles
1	Process Safety Progress	19
2	Journal of Loss Prevention in the Process Industries	13
3	Process Safety and Environmental Protection	6
4	Education for Chemical Engineers	5
5	Chemical Engineering Transactions, The Publication of AIDIC	3
6	Safety Science	3

7	Journal of Safety Research	3
8	Chemical Engineering Progress	2
9	Chemical Engineering Technology	2
10	Chemical Health and Safety	2
11	Journal of Hazardous Materials	2
12	Institution of Chemical Engineers (IChemE)	2
13	Current Opinion in Chemical Engineering	1
14	International Symposium on Advances in Technology Education	1
15	Journal of European Industrial Training	1
16	Occupational Health and Safety	1
17	Journal of Professional Issues on Engineering Education and Practice	1
18	Procedia Engineering	1
19	Science and Engineering Ethics	1
20	IIE Transactions on Occupational Ergonomics and Human Factor	1
21	AICHE Journal	1
22	Chemical Engineering Education	1
23	Computers Chemical Engineering	1
24	Proceedings of the Canadian Engineering Education Association	1
25	Cognition, Technology and Work	1
26	Journal of Integrated Security Science	1
27	Reliability Engineering and System Safety	1
28	Q Science Proceedings	1
29	Procedia Computer Science	1
30	Computers and Industrial Engineering	1

Furthermore, professional literature used for this review article includes textbooks, conference papers and records from reputed professional organizations, such as the Chemical Safety and Hazard Identification Board (CSB), the Loss Prevention and Safety Promotion Symposium series, the Centre of Chemical Process Safety (CCPS), UK Health and Safety Executive (HSE), Dutch National Institute for Public Health and the Environment (RIVM) and American Institute of Chemical Engineers (AICHE). Professional literature in process safety training was limited in supporting extensive review. Hence, grey literature obtained through the websites of professional organisations was utilised to compensate for the inadequacy of professional literature. The relevancy of the chosen literature was established through a filtering process using inclusion and exclusion criteria, which serves as an eligibility background for this review. These criteria aimed to cover literature published from the year 1990 onwards, and those published in the English language. In addition, guide words used in gathering content for this review include ‘process safety education’, ‘process safety education model’, ‘process safety supporting learning aids’, ‘process safety education curriculum content’, ‘process safety education methodology’, ‘process safety education accreditation body’, ‘process safety scientific research’, ‘process safety education collaboration’, ‘process safety training’, ‘process safety training curriculum’, and ‘process safety competence’.

3. Research findings

3.1 Role of Accreditation

Process safety education programs are often subject to an evaluation of their curricula by an accredited body. Institutions offering process safety education are mandated to fulfil accreditation conditions laid out by the same body. Thus, engineering undergraduate programs and master's degree programs are endorsed by reputed accreditation bodies, in line with set standards and guidelines. These conditions include checks on the curriculum, the methodology, the learning outcomes, and are frequently regarded in organisations as necessary for the advancement of a professional career in the CPI (IChemE, 2015).

The accreditation bodies designated for this role include the Accreditation Board for Engineering and Technology (ABET) in the United States of America, the Canadian Engineering Accreditation Board (CEAB) in Canada, the Institution of Chemical Engineers (IChemE) in the United Kingdom, the Engineers Australia Accreditation Board in Australia as well as governmental accreditation agencies active in single countries. Table 3 provides an overview of the references related to the accreditation bodies. The roles of these bodies can vary, but they often have the same goals; for example, ABET includes a discussion of the restructuring of process safety concepts in the curriculum of undergraduate chemical engineering programs (Dee et al., 2015). Similarly, in Europe, plant and process safety education programs at both undergraduate and master's degree level are developed in accordance with the Bologna educational system (Cortés et al., 2011; Schonbucher et al., 2013).

Table 3. Process safety education accreditation found in scientific literature

Accreditation	Reference
Accreditation Board for Engineering and Technology (ABET)	Pintar 1999, Willey et al., 2010, McKay et al., 2011, Crowl 2012, Wu et al., 2012, Amyotte 2013, Shallcross 2013, Spicer et al., 2013, Pasman et al., 2014, Véchot et al., 2014, AICHE 2015, Dee et al.,2015, Dixon and Kohlbrand 2015, Mannan et al., 2015, Amyotte et al., 2016
Canadian Engineering Accreditation Board (CEAB)	Norval et al., 2010, Amyotte 2013, Amyotte et al., 2016
Hong Kong Institution of Engineers Professional Accreditation Body	McKay et al., 2011
Engineers Australia Accreditation Board	Shallcross 2013

In summary, accreditation can be very important for universities to stress the importance of certain contents in curriculums, and it can be used to stress and improve process safety education programs.

3.2 Curriculum found in scientific literature

Curriculum development for process safety education has been proposed over the years by numerous authors. Such proposals include the integration of safety culture into the safety curriculum, consistency with accreditation (ABET) directives, adoption of recommendations provided by researchers and practitioners, etc. (Hendershot and Smades, 2007; Louvar and Hendershot, 2007; Crowl, 2012). The development of a curriculum which is supported by strategic lecture delivery has also been cited as an essential requirement for effective process safety education (Ferjencik, 2007), as well as the prioritization of curriculum development and a continuous education, as recommended by Eckhoff (1994). Other relevant contributions in curriculum development include the adoption of the Plant and Process Safety (PPS) curriculum by Dechema (German Chemical Engineering Network) recommendation (Schmidt, 2013) and the development of safety and loss prevention curricula in chemical engineering programs of French universities (Perrin and Laurent, 2008). Also, a special contribution has been made by Trevor Kletz on the curriculum development of an inherently safer design (Mannan 2012).

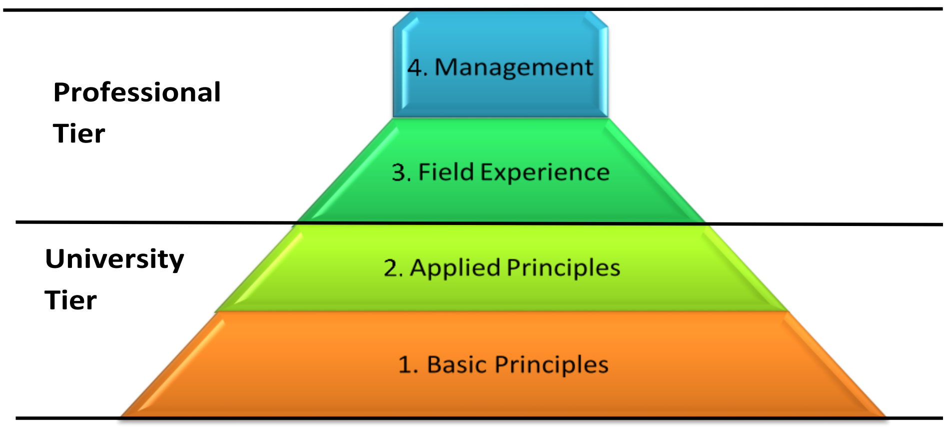
Despite stakeholders' participation in curriculum development, the implementation of such curriculums amongst universities is seen as ineffective (McKay et al., 2011). At present, generally-accepted curricula for safety education do not seem to exist in university and industry (Krause 2016; Rae, 2016). Currently, the courses offered in most universities include asset integrity and reliability, chemistry, hazard and risk assessment, fire and explosion modelling, and process safety management (see also the Appendix). Whilst a curriculum can be revised in the event of a process incident, as it was for example in case of the so-called 'T2 laboratory reactive incident' in the USA (CSB 2009; Spicer et al., 2013), an overcrowded curriculum poses a threat to any revision (Hendershot et al., 1999; Saleh and Pendley, 2012; Dixon and Kohlbrand, 2015).

3.3 Teaching Methodology found in scientific literature

In delivering a process safety curriculum, a structured teaching approach is used to aid the understanding of concepts. This approach includes the integration of process safety concepts into existing courses (Hendershot et al., 1999; Mannan et al., 1999; Osborn, 1999; Pintar, 1999; Willey, 1999; Shacham et al., 2006; Hendershot & Smades, 2007; Perrin & Laurent, 2008; Willey et al., 2010; Cortés et al., 2011; Crowl, 2012; Véchot et al., 2014; Dee et al., 2015 Meyer, 2015; Benintendi, 2016). Examples of this can be found in undergraduate programs addressing safety and hazard management as well as chemistry (Hendershot et al., 1999; Krause, 2016). Other approaches include the delivery of process safety notions in a stand-alone course (Pintar, 1999; Crowl, 2012; Dee et al., 2015) and/ or selection based on specific process safety courses (Perrin and Laurent, 2008; Cortés et al., 2011; Véchot et al., 2014).

Furthermore, these teaching approaches adopt different learning strategies which can include storytelling, evidence-based teaching, and safety information sharing (Shallcross, 2013; Cheah, 2016; Rae, 2016). These teaching strategies promote safety competency, technical design creativity, decision making and accident prevention (Saleh and Pendley, 2012). Similarly, as shown in Figure 2, process safety education can be formulated as an example of tier-based learning (Benintendi, 2016). This approach conforms to the process safety model of Figure 1. The basic and applied principles correlate with undergraduate programs combined with internships, and master's degree program respectively, while the field experience and process safety management correlates with OJT and CPD respectively. Recent studies show that there are only a limited number of universities where process safety is taught as a standalone course (Pasman et al., 2014; Krause, 2016).

Figure 2. The learning process - learning pyramid model (Benintendi, 2016)



3.4 Process safety research found in scientific literature

Research in process safety education is a key approach for promoting the development of scientific knowledge and innovative technology in the process industry. Therefore, adequate attention is required for sustainable Research and Development (R&D). Furthermore, research helps the advancement of the process industry by developing solutions to existing industry challenges. The process safety field of research includes asset integrity and reliability, chemistry-related courses, design, hazard identification and risk analysis, human factor as well as others (see also Table 4). These research domains promote process safety competences which are crucial to prevent major accidents in the process industry (Gibson, 1999; Schmidt, 2013; Meyer, 2015). Research centres are often established in universities to enhance scientific knowledge and to promote industry best practices.

Table 4. Process safety research domain found in scientific literature

Scientific research	Reference
Fire and explosion studies, Design	Gibson 1999
Chemistry related courses and Process control	Mannan et al. 1999
Safety performance and sustainability	Willey 1999, Knegtering and Pasman 2009, Pfeil et al. 2013, Schonbucher et al., 2013
Risk analysis and Management	Lundin and Jönsson 2002

Process safety education	Mckay et al. 2011, Schonbucher et al., 2013
Asset integrity and reliability, Chemistry related courses, Design, Hazard identification and risk analysis, Human factor, Incident management, Risk management, Safety culture, Process safety management knowledge	Mannan 2012, Amyotte 2013, Pasman et al. 2014
Chemistry related courses, Design, Fire and explosion studies, Hazard identification and risk analysis, Risk decision making, Security, Safety performance indicator	Mannan et al. 2012
Asset integrity and reliability, Chemistry related courses, Design, Fire and explosion studies, Hazard identification and risk analysis, Human factor, Incident management, Risk management, Safety culture, Safety management	Pasman et al. 2014
Safety management	Nesheim and Gressgård 2014, Krause, 2016
Hazard identification and risk analysis, Incident management	Véchot et al., 2014
Design, Hazard identification and risk analysis	Dee et al. 2015, Meyer 2015

3.5 Process safety collaboration found in scientific literature

Process safety collaboration refers to cooperation amongst academia, industry and authorities to foster the learning objectives required for adequate process safety. It should be noted that achieving effective collaboration requires substantial effort from university lecturers, industry professionals, accreditation bodies, governmental and regulatory agencies and others. Moreover, partnerships in a wider scope can be optimised by sharing information, internship opportunities, development of curricula, research opportunities and funding (see also Table 5).

Figure 3 provides an overview of collaboration topics belonging to the interfaces between universities, industry and government. Evidence of such collaboration in process safety education include amongst others (i) collaboration between the Dow Chemical company and AIChE on undergraduate process safety curricula upgrades and the organisation of process safety boot camps (AICHE, 2015), (ii) cooperation between Safety and Chemical Engineering education (SACHE) and ABET, (iii) university process safety curricula upgrades, (iv) development of SACHE process safety education websites and products, (v) the establishment of workshops for university lecturers (Willey, 1999; Louvar & Hendershot, 2003; Louvar, 2009; Crowl, 2012; Spicer et al., 2013), (vi) collaboration between industry (by means of the European Federation of Chemical Engineering), academia and government bodies on the organisation of a permanent working party on loss prevention and sdafety promotion in the process industries, and the organisation of a 3-yearly loss prevention symposium (Pasman et al., 2014), and (vii) Minerva Canada collaboration with universities, government and industry on the development of process safety education products (Norval et al., 2010).

Aside from strategic involvements between the different parties, other benefits of collaboration are reflected by the promotion of competences and the assumable prevention of major accidents (Reniers and Amyotte 2012; Pfeil et al., 2013). Also, it is obvious that the interface amongst university, process industry and government agencies stimulates strategic collaboration objectives of funding, safety performance, curricula development, research and many more. (Figure 3).

Table 5. Process safety education areas of collaboration found in scientific literature

Collaboration	Reference
Research	Gibson 1999, Mannan et al. 1999, Mannan 2012, Mannan et al. 2012, Lundin and Jönsson 2002, Wu et al. 2012
CPI safety performance and sustainability	Osborn 1999, Saleh and Pendley 2012, Nesheim and Gressgård 2014, Pasman et al., 2014, Benintendi 2016
Funding	Mannan et al. 1999, Schmidt 2013
Process safety publications	Pintar 1999
Curriculum development	CSB 2009, Willey et al. 2010, Mckay et al. 2011, Crowl 2012, Degreve and Berghmans, 2012, Amyotte 2013, Spicer et al. 2013, AICHE 2015, Mannan et al., 2015
Internship	Perrin and Laurent 2008, Schmidt 2013 Véchot et al., 2014
Shareholders (shares and assets)	Wasileski 2009
Teaching	Mannan et al. 1999, Perrin and Laurent 2008, Norval et al., 2010, Crowl 2012, Degreve and Berghmans, 2012, Pitt 2012, Saleh and Pendley 2012, Schmidt 2013, Véchot et al., 2014, AICHE 2015, Dixon et al., 2015

Figure 3. Process safety collaboration interface

Figure 3 indicates that there are different levels of collaboration between the different parties involved. It seems that the heaviest weight of level of collaboration is situated between university and industry.

3.6 Process safety competence found in scientific literature

Modern process installations are becoming more complex and their operation requires high-level competences. Against this background, having a safety education curriculum that demonstrates efficient learning objectives can be regarded as a necessary approach for adequate process safety knowledge application (Elangovan et al. 2005; Knegtering and Pasman, 2009; EFCE, 2010; Pitt, 2012; Wu et al., 2012; IChemE, 2015; Benintendi, 2016). To meet the increasing need for process safety competence, contributing factors such as research, funding, education, standards and guidelines for best operating practices are becoming crucial (Pfeil et al., 2013). These factors were recommended by the German Society for Chemical Engineering and Biotechnology/ German Society for Process and Chemical Engineering (DECHEMA/GVC) report (2004), the Dutch Hazardous Substances Council of the Netherlands (AGS) report (2009) and the European Congress of Chemical Engineering (ECCE) 8th session (2011). Furthermore, the promotion of process industry competences have attracted the development of master's programs as witnessed for instance at KU Leuven in Belgium and Lund University in Sweden (Lundin & Jönsson, 2002; Degreve and Berghmans, 2012).

The use of appropriate learning methods is a requirement for improving process safety competences (Mannan et al., 2012). Aside from information sharing, other learning methods include the integration of process hazard analysis, case studies, employee training and research. It can be assumed that the development of process safety competence stems from knowledge application, gained through process safety education and training. This assumption needs to be further investigated, but it should be mentioned that it conforms with a postulation on high performance ranking resulting from education, experience and training (Nesheim and Gressgård, 2014).

3.7 Process safety training found in scientific and professional literature

The training methods adopted by process safety training programs are intended to enhance their effectiveness. Apart from skill-based training, other methods include performance-based training, mentoring programs, team study, web-based training and others (Cusimano, 1995; Young & Hodges, 2012; Taylor et al., 2016).These methods are regularly evaluated to assess training effectiveness (Cooper and Cotton, 2000; Haesle et al. , 2009). To meet the needs of the process industry, the restructuring of safety training is crucial (Louvar, 2008). This is evident in the formulation of process safety training programs (Zaloom and Ramachandran, 1996; Myers et al., 2008; Hendershot et al., 2011; Mannan et al., 2015). Furthermore, process safety trainings aids the performance of operators in the process industry (Hub, 1999; Gatfield, 1999; Cann, 2001; Shacham et al., 2006; Wasileski, 2009; Nazir and

Manca, 2015; Yamamoto, 2015). Such training includes dynamic simulation, cognitive safety training, hazard identification and others.

3.8 Process safety training curriculum found in scientific and professional literature

In the chemical process industry, process safety training requirements exist as a structured curriculum. The development of such a curriculum requires a concerted effort, most especially by the industry. A process safety curriculum could include asset integrity and reliability, fire and explosion studies, hazard identification, risk analysis and process safety management. (see Table 6). Furthermore, the curriculum can be implemented with the aid of a methodology that aims to deliver training objectives for industry professionals. Also, the process industry tends to develop training curriculums according to their needs (Spicer et al., 2013). Such training curricula combine with learning aids to enhance training assimilation. The learning aids identified for effective training purposes include multimedia, MP3 players, web-based teaching, computer aided assessment, simulations and more (Moon et al.,1998; Myers et al., 2008). It is logical to note that apart from professional trainings, university education plays a crucial role in knowledge application by promoting basic concepts and theories required in the industry.

Table 6. Process safety professional training curriculum (Scientific/ Professional literature)

Professional curricula/ module content	Institute providing material on the topic, or reference
Asset integrity and reliability	Institute of Hazard Prevention, PetroSkills, CCPS, IChemE 2017, Process Improvement Institute, Risknowlogy
Chemistry related courses	ioMosaic
Design	Myers et al., 2008, PetroSkills, Yamamoto 2015, CCPS, Exida 2017, IChemE 2017, ioMosaic, Risknowlogy, TUV Rheinland
Economics	CCPS
Fire and Explosion Studies	Chris Mee Group, PetroSkills, ABB, Energy Institute, Exida 2017, IChemE 2017, ioMosaic
Hazard Identification and Risk Analysis	Cann 2001, Wasileski 2009, European Commission, Chris Mee Group, Institute of Hazard Prevention, PetroSkills, Yamamoto 2015, Georgia Tech Professional Education, ABB, CCPS, Competency Training, Dekra Insight, Emerson, Hendershot et al., 2011, Exida 2017, IChemE 2017, ioMosaic, PrimaTech, Process Improvement Institute, TUV Rheinland
Human Factor	European Commission, ABB, Energy Institute, IChemE, PrimaTech, Process Improvement Institute
Incident Management	Cann 2001, Hendershot et al., 2011, European Commission, PetroSkills, Yamamoto 2015, CCPS, Competency Training, Emerson, Process Improvement Institute

Process Control	European Commission, Institute of Hazard Prevention, PetroSkills, ABB, , Exida 2017, ioMosaic, PrimaTech, Process Improvement Institute, Risknowlogy, TUV Rheinland
Process Safety Management	Cann 2001, Elangovan et al., 2005, Hendershot et al., 2011, Young and Hodges 2012, Technology ED, European Commission, Institute of Hazard Prevention, Georgia Tech Professional Education, ABB, ABS Group, CCPS, Cogent Skills, Competency Training, Dekra Insight, Emerson, Energy Institute, Health and Safety Laboratory, IChemE 2017, ioMosaic, PrimaTech, Process Improvement Institute, Red Vector
Regulation	European Commission, Institute of Hazard Prevention, Georgia Tech Professional Education, ABB, ABS Group, CCPS, Competency Training, Exida 2017, ioMosaic, Risknowlogy, TUV Rheinland
Security	PrimaTech
Software Programs	Zaloom and Ramachandran 1996, Moon et al., 1998, Nazir and Manca 2015, Yamamoto 2015, PrimaTech

4. Discussion

As it stands, the education of process safety can only be achieved in universities and in industry, and requires an unbiased analysis of its contributing elements. The process safety education model has played an important role in the advancement of process safety in the chemical process industry. In the UK university system for example, the IChemE accreditation body performs accreditation for process safety education programs in higher education institutions (IChemE, 2015). Although the accreditation bodies vary from one country to another, accreditation ensures the standardisation of process safety curricula used within universities. However, it has been observed that the accreditation of process safety education only applies to university-based programs, and does not exist in the process industry. Thus, it is cogent to question whether all programs related to process safety education are adequately assessed and approved by accreditation bodies.

According to IChemE (2015), process safety education accreditation bodies require universities to proof their curriculum learning outcomes as a condition. This requirement function firstly demonstrates the credibility of such process safety education programs in sustaining the best industrial practices and secondly serves as a proof to the accreditation assessors. Furthermore, the accreditation of process safety education curricula evaluates sufficiency of preventive strategies and techniques necessary for the prevention of major accidents in the process industries. The Accreditation Board for Engineering and Technology (ABET) in the United States of America seems to demonstrate dominance in that country with most undergraduate chemical engineering programs containing process safety related courses subscribing to it. Furthermore, the Bologna Educational System is widely accepted in Europe, and not imposing any demands with respect process safety as with no other specific disciplinary field.

Curriculum contents evidently remains a pivotal element of process safety education, as it is necessary for the prevention of major accidents, and for the attainment of relevant knowledge by process safety experts (researchers and professionals). Furthermore, the development of a curriculum should meet with an accreditation body's conditions as well as industry needs (Amyotte, 2013). The learning outcomes from process safety curricula aim to boost efficient performance of safety operations in the CPI.

Literature suggests that when process safety curricula are utilised within university and industry, they tend to lean towards a similar or comparable content. It is also noted, that curricula for both university and industry assign priority to hazard identification, risk analysis, incident management, and process safety management courses. These courses are thus considered very important to gain process safety knowledge. University curricula assign less priority to security and software programs, while professional curriculums, on the other hand, assign less priority to chemistry-related courses, economics, and also less attention (similar to university curricula) to security, even when security threats are becoming prevalent in our societies since 9/11 (Reniers and Amyotte, 2012). It is against this backdrop that concepts such as the design-based safety principles and safety & security clusters were developed (Reniers and Amyotte 2012; Reniers & Khakzad, 2017).

The teaching approaches of process safety help to strengthen knowledge applications, improve safety culture, and foster prevention strategies. However, in most universities there exists a strong preference for the integration of process safety courses into an existing program, as opposed to teaching process safety as a dedicated course. This situation is attributed to a lack of trained professional lecturers in this field of study (Pitt, 2012). To address this gap, professionals from the industry could support universities by teaching process safety as a dedicated course (Dixon and Kohlbrand, 2015).

The development of process safety education learning aids within the universities and industries has been strongly supported by international organisations; for example, in the USA there exist the Center for Chemical Process Safety (CCPS), SAfety and Chemical Engineering education (SAChE), the U.S Chemical Safety and Hazard Investigation Board (CSB), the Mary Kay O Connor Process Safety Center and the American Institution of Chemical Engineers (AIChE). Similarly, in Europe, the following organisations can be found: the European Process Safety Centre (EPSC), the European Federation of Chemical Engineering (EFCE), the Institution of Chemical Engineers (IChemE) and the Safety to Safety (S2S) initiative. In Canada, the Canadian Society for Chemical Engineering (CSChE) and Minerva Canada Safety Management Education exist. In this review, universities seem to mostly utilise SACHE products, CSB products and process safety related software programs.

Collaboration in process safety education is witnessed in the form of research, funding, curriculum development, internship, teaching, and consultation. However, process safety education collaboration varies both in scope and in stakeholders' involvement. In this review, the industry, governmental agencies and academia were identified as strategic collaborators for process safety education, and collaboration in teaching, research and curriculum development were found to be most important for the advancement of process safety education.

In the process industry, the performance of tasks is expected to be as efficient as possible, and this is dependent on process safety competence. The 'competence' originates from process safety education and training, conducted both in the university and industry respectively. Process safety competence can be understood as the main objective of process safety education. Competence is identified as key element which is common and central, and is defined as such at all levels from bachelor degree in university education to that of a process safety inspectors in government regulatory agencies. Process safety training programs promote professional capabilities in terms of operation, and although the timeline of this training varies, the learning objectives are expected to demonstrate process safety competence.

5. Conclusions and Recommendations

In the daily operations of the process industry, competence is required for safe and efficient operations. This is achieved through a teaching approach which utilises an appropriate methodology and learning aids, consistent with applicable accreditation programs and a rich curriculum developed from the needs of the chemical process industry. This review analysed areas impacting process safety education and professional training.

Process safety education in the USA was found to be integrated into undergraduate engineering programs, and especially in chemical engineering (Pintar, 1999; Willey, 1999; Louvar and Hendershot, 2003; Louvar, 2009; Willey et al., 2010; Crowl, 2012; Spicer et al., 2013). Integration of this course limits the viability of process safety education at an undergraduate level, especially in Germany (Krause, 2016), resulting in fewer universities offering this program at both undergraduate and master's degree level. Consequently, process safety courses which exist as a separate course have attracted little attention (Pasman et al., 2014), as is also the case for programs specifically addressing process safety or even safety engineering as an independent discipline.

The main gap identified in this review is the inconsistency in the curriculum content of process safety education used in universities and industries. Universities tend to adopt a process safety curriculum separately from one another, despite offering similar programs (Krause, 2016; Rae, 2016). This situation also applies to process safety professional training in the industry (Spicer et al., 2013). This observation indicates the support for a kind of tailor-made curriculum, be it a very broad one, rather than a generic structured curriculum.

Furthermore, accreditation of the process safety curriculum in most universities lacks effective implementation, and adjusting existing programs to accommodate process-safety accredited courses are met with resistance because of existing, overloaded curricula (Hendershot et al., 1999; Saleh and Pendley, 2012; Dixon and Kohlbrand, 2015). This study further reveals that the industry should identify its needs and collaborate with accreditation bodies and universities for effective implementation of its process safety curriculum needs.

The main challenge in compiling this review was the inadequate extent of professional publications supporting process safety training as opposed to process safety education. This gap can be attributed to the proprietary information status placed by the industry on related publications or the non-disclosure status of process safety professional training which is carried out within the industry. As such, grey literature was extensively utilized to address this gap.

Appendix. Process safety education curriculum from scientific literature

Curriculum/ Module content	Reference
Asset integrity and reliability	Eckhoff 1994, Mannan et al., 1999, Norval et al., 2010, Degreve and Berghmans 2012, Benintendi 2016
Chemistry related courses	Eckhoff 1994, Hendershot et al., 1999, Mannan et al., 1999, Osborn 1999, Pintar 1999, Willey 1999, Shacham et al., 2006, Ferjencik 2007, Perrin and Laurent 2008, EFCE 2010, Willey et al., 2010, Degreve and Berghmans 2012, Pitt 2012, Amyotte 2013, Shallcross 2013, Spicer et al., 2013, Véchot et al., 2014, Dee et al.,2015, Dixon and Kohlbrand 2015, Benintendi 2016, Krause 2016
Design	Hendershot et al., 1999, Mannan et al., 1999, Pintar 1999, Louvar and Hendershot 2003, Shacham et al., 2006, Ferjencik 2007, Dadkhah 2008, Perrin and Laurent 2008, EFCE 2010, Norval et al., 2010, Cortés et al., 2011, Mannan 2012, Pitt 2012, Amyotte 2013, Schmidt 2013, Schonbucher et al., 2013, Shallcross 2013, Spicer et al., 2013, Véchot et al., 2014, Dee et al.,2015, Dixon and Kohlbrand 2015, IChemE 2015, Cheah 2016
Economics	Lundin and Jönsson 2002, Norval et al., 2010, Degreve and Berghmans 2012, Pitt 2012, Saleh and Pendley 2012, Shallcross 2013, Dixon and Kohlbrand 2015, Meyer 2015
Fire and Explosion studies	Eckhoff 1994, Hendershot et al., 1999, Mannan et al., 1999, Osborn 1999, Pintar 1999, Willey 1999, Ferjencik 2007, Perrin and Laurent 2008, Norval et al., 2010, Degreve and Berghmans 2012, Pitt 2012, Amyotte 2013, Schmidt 2013, Schonbucher et al., 2013, Shallcross 2013, Véchot et al., 2014, Dee et al.,2015, Dixon and Kohlbrand 2015, IChemE 2015, Benintendi 2016, Krause 2016

Hazard Identification and Risk Analysis	Eckhoff 1994, Hendershot et al., 1999, Mannan et al., 1999, Pintar 1999, Lundin and Jönsson 2002, Louvar and Hendershot 2003, Shacham et al., 2006, Ferjencik 2007, Perrin and Laurent 2008, EFCE 2010, Norval et al., 2010, Cortés et al., 2011, McKay et al., 2011, Degreve and Berghmans 2012, Mannan et al., 2012, Pasman et al., 2012, Pitt 2012, Saleh and Pendley 2012, Amyotte 2013, Schmidt 2013, Schonbucher et al., 2013, Shallcross 2013, Spicer et al., 2013, Pasman et al., 2014, Véchot et al., 2014, Dee et al.,2015, Dixon and Kohlbrand 2015, IChemE 2015, Meyer 2015, Benintendi 2016, Cheah 2016, Krause 2016
Human Factor	Eckhoff 1994, Mannan et al., 1999, Ferjencik 2007, Norval et al., 2010, Pitt 2012, Saleh and Pendley 2012, Shallcross 2013, Pasman et al., 2014, Shallcross 2014, Dixon and Kohlbrand 2015,
Incident Management	Eckhoff 1994, Osborn 1999, Pintar 1999, Willey 1999, Ferjencik 2007, Perrin and Laurent 2008, Norval et al., 2010, Willey et al., 2010, McKay et al., 2011, Mannan 2012, Mannan et al., 2012, Pitt 2012, Saleh and Pendley 2012, Amyotte 2013, Shallcross 2013, Pasman et al., 2014, Véchot et al., 2014, Dee et al.,2015, Dixon and Kohlbrand 2015, Benintendi 2016, Cheah 2016, Krause 2016, Rae 2016
Process Control	Mannan et al., 1999, Pintar 1999, Ferjencik 2007, Degreve and Berghmans 2012, Pitt 2012, Saleh and Pendley 2012, Schmidt 2013, Schonbucher et al., 2013, Shallcross 2013, Véchot et al., 2014, Dee et al.,2015, IChemE 2015, Benintendi 2016, Cheah 2016, Krause 2016
Process Safety Management	Mannan et al., 1999, Ferjencik 2007, EFCE 2010, Norval et al., 2010, Degreve and Berghmans 2012, Pitt 2012, Amyotte 2013, Schmidt 2013, Schonbucher et al., 2013, Shallcross 2013, Pasman et al., 2014, Véchot et al., 2014, IChemE 2015, Cheah 2016, Krause 2016
Regulation	Lundin and Jönsson 2002, Ferjencik 2007, Perrin and Laurent 2008, Norval et al., 2010, Cortés et al., 2011, Degreve and Berghmans 2012, Pitt 2012, Amyotte 2013, Shallcross 2013, Pasman et al., 2014, Véchot et al., 2014, Dixon and Kohlbrand 2015, IChemE 2015, Meyer 2015, Krause 2016
Risk Decision Making	Mannan et al., 1999, Saleh and Pendley 2012
Security	Dee et al.,2015
Software program	Pintar 1999

References

Majid Abdul, N. D., Mohd Shariff, A., & Mohamed Loqman, S. (2016). Ensuring emergency planning & response meet the minimum Process Safety Management (PSM) standards requirements. *Journal of Loss Prevention in the Process Industries*, *40*, 248–258. https://doi.org/10.1016/j.jlp.2015.12.018

AICHE. (2015, December). DOW MAKES LEADERSHIP GIFT TO LAUNCH MAJOR PROCESS SAFETY EDUCATION INITIATIVE. *Chemical Engineering Progress*, p. 53.

Amyotte, P. R. (2013). Process safety educational determinants. *Process Safety Progress*, *32*(2), 126–130. https://doi.org/10.1002/prs.11598

Amyotte, P. R., Berger, S., Edwards, D. W., Gupta, J. P., Hendershot, D. C., Khan, F. I., … Willey, R. J. (2016). Why major accidents are still occurring. *Current Opinion in Chemical Engineering*, *14*, 1–8. https://doi.org/10.1016/j.coche.2016.07.003

Aziz, H. A., Shariff, A. M., Rusli, R., & Yew, K. H. (2014). Managing process chemicals, technology and equipment information for pilot plant based on Process Safety Management standard. *Process Safety and Environmental Protection*, *92*(5), 423–429. https://doi.org/10.1016/j.psep.2014.02.011

Baybutt, P. (2016). Insights into process safety incidents from an analysis of CSB investigations. *Journal of Loss Prevention in the Process Industries*, *43*, 537–548. https://doi.org/10.1016/j.jlp.2016.07.002

Benintendi, R. (2016). The bridge link between university and industry: A key factor for achieving high performance in process safety. *Education for Chemical Engineers*, *15*, 23–32. https://doi.org/10.1016/j.ece.2016.02.002

Cann, N. (2001). USE OF THE SAFETY CASE AS A TRAINING TOOL TO DISPERSE CORPORATE KNOWLEDGE. *IChemE*, *148*, 655–663.

Cheah, S.-M. (2016). EVIDENCE-BASED FLIPPED CLASSROOM CASE STUDY – TEACHING CHEMICAL PROCESS SAFETY. *International Symposium on Advances in Technology Education*. Retrieved from https://www.researchgate.net/publication/308265915_EVIDENCE-BASED_FLIPPED_CLASSROOM_CASE_STUDY_-_TEACHING_CHEMICAL_PROCESS_SAFETY, p.1-6

Cooper, M., & Cotton, D. (2000). Safety training – a special case? *Journal of European Industrial Training*, *24*(9), 481–490. https://doi.org/10.1108/03090590010358205

Cortés, J. M., Pellicer, E., & Catala, J. (2011). Integration of occupational risk prevention courses in engineering degrees: Delphi study. *Journal of Professional Issues in Engineering Education & Practice*, *138*(1), 31–36.

Cox, S. J., & Tart, N. R. (1991). *Reliability, Safety and Risk Management; An integrated Approach*. Butterworth- Heinemann, p.272-274

Crowl, D. (2012a, April). Process Safety Education: Meeting the New ABET Requirements. *Chemical Engineering Progress*, p. 19.

Crowl, D., & Louvar, J. (2002). *Chemical Process Safety, Fundamentals with Applications, p.70*.

CSB. (2009). U.S. CHEMICAL SAFETY AND HAZARD INVESTIGATION BOARD INVESTIGATION REPORT T2 LABORATORIES, INC. RUNAWAY REACTION. U.S Chemical Safety and Hazard Investigation Board (CSB). Retrieved from http://www.csb.gov/t2-laboratories-inc-reactive-chemical-explosion/

Cusimano, J. (1995). Chemical Plant Empowers Work Force To Initiate Process Safety Training. *Occupational Health and Safety*, p. 46.

Dee, S. J., Cox, B. L., & Ogle, R. A. (2015). Process safety in the classroom: The current state of chemical engineering programs at US universities. *Process Safety Progress*, *34*(4), 316–319. https://doi.org/10.1002/prs.11732

Degreve, J., & Berghmans, J. (2012). Master of Science in Safety Engineering at KU Leuven, Belgium. *Procedia Engineering*, *45*, 276–280. https://doi.org/10.1016/j.proeng.2012.08.157

Ditchburn, S., & David, D. (2006). Understanding major accident hazard management-the more you know, the more you know you don’t know. In *INSTITUTION OF CHEMICAL ENGINEERS*

SYMPOSIUM SERIES (Vol. 151, p. 861). Institution of Chemical Engineers; 1999. Retrieved from http://www.ichemeoncampus.org/communities/subject_groups/safety%20and%20loss%20prevention/resources/hazards%20archive/~/media/Documents/Subject%20Groups/Safety_Loss_Prevention/Hazards%20Archive/XIX/XIX-Paper-59.pdf

Dixon, D. J., & Kohlbrand, H. T. (2015). Lending industrial experience through reactive hazard examples in university safety instruction. *Process Safety Progress*, *34*(4), 360–367. https://doi.org/10.1002/prs.11785

Eckhoff, R. K. (1994). Process safety-a persistent challenge to educators. *Journal of Loss Prevention in the Process Industries*, *7*(4), 266.

EFCE. (2010, August). Recommendations for Chemical Engineering Education in a Bologna Three Cycle Degree System. EFCE, p.1-9.

Elangovan, R. K., Mohammed, K. P., & Mohan, S. (2005). Effectiveness of the designed safety education programme modules by their implementation in selected industries. *Journal of Loss Prevention in the Process Industries*, *18*(4–6), 553–557. https://doi.org/10.1016/j.jlp.2005.07.019

Exida. (2017). exida Training - Functional Safety, ICS Cybersecurity, Alarm Management, CFSE. Retrieved April 3, 2017, from http://www.exida.com/Training

Ferjencik, M. (2007). Best starting point to comprehensive process safety education. *Process Safety Progress*, *26*(3), 195–202. https://doi.org/10.1002/prs.10183

Gatfield, D. (1999). Can cognitive science improve the training of industrial process operators? *Journal of Safety Research*, *30*(2), 133–142.

Gibson, N. (1999). Process safety–a subject for scientific research. *Process Safety and Environmental Protection*, *77*(3), 149–153.

Guntzburger, Y., Pauchant, T. C., & Tanguy, P. A. (2016). Ethical Risk Management Education in Engineering: A Systematic Review. *Science and Engineering Ethics*. https://doi.org/10.1007/s11948-016-9777-y, p.1-17

Haesle, J., Devlin, C., & Mccavit, J. L. (2009). Improving process safety by addressing the human element. *Process Safety Progress*, *28*(4), 325–330. https://doi.org/10.1002/prs.10326

Hendershot, D. C., Herber, J., & King, G. M. (2011). CCPS process safety beacon: A tool to promote process safety awareness for front line plant workers. *Process Safety Progress*, *30*(4), 405–407. https://doi.org/10.1002/prs.10491

Hendershot, D. C., Louvar, J. F., & Kubias, F. O. (1999). Add chemical process safety to the chemistry curriculum. *Chemical Health and Safety*, *6*(1), 16–22.

Hendershot, D. C., & Smades, W. (2007). Safety culture begins in the classroom. *Process Safety Progress*, *26*(2), 83–84. https://doi.org/10.1002/prs.10200

Hopkins, A. (2015). The cost–benefit hurdle for safety case regulation. *Safety Science*, *77*, 95–101. https://doi.org/10.1016/j.ssci.2015.03.022

HSE. (2011, December). COMAH Competent Authority Inspection of Competence Management Systems at COMAH Establishments. Health and Safety Executive. Retrieved from www.hse.gov.uk

HSE. (2012, October). Competent authority guidance for inspectors on emergency arrangements for COMAH establishments. Health and Safety Executive. Retrieved from www.hse.gov.uk

HSE. (2015, September). Understanding COMAH: What to expect from the Competent Authority. Health and Safety Executive. Retrieved from www.hse.gov.uk

Hub, L. (1999). Simulation Program for Hazard Training and Safety Evaluation of Chemical Processes. *Chemical Engineering Technology*, *22*(9), 740–742.

Hurme, M., & Rahman, M. (2005). Implementing inherent safety throughout process lifecycle. *Journal of Loss Prevention in the Process Industries*, *18*(4–6), 238–244. https://doi.org/10.1016/j.jlp.2005.06.013

IChemE. (2015, November). Accreditation of Chemical Engineering Programmes - A guide for higher education providers and assessors., IChemE, p.4-25,.

IChemE. (2017). IChemE Safety Centre | Training. Retrieved April 2, 2017, from http://www.ichemesafetycentre.org/isc-training.aspx

Khan, F. I., & Abbasi, S. A. (1999). Major accidents in process industries and an analysis of causes and consequences. *Journal of Loss Prevention in the Process Industries*, *12*(5), 361–378.

Kidam, K., Hussin, N. E., Hassan, O., Ahmad, A., Johari, A., & Hurme, M. (2014). Accident prevention approach throughout process design life cycle. *Process Safety and Environmental Protection*, *92*(5), 412–422. https://doi.org/10.1016/j.psep.2014.05.006

Kluge, A., Nazir, S., & Manca, D. (2014). Advanced Applications in Process Control and Training Needs of Field and Control Room Operators. *IIE Transactions on Occupational Ergonomics and Human Factors*, *2*(3–4), 121–136. https://doi.org/10.1080/21577323.2014.920437

Knegtering, B., & Pasman, H. J. (2009). Safety of the process industries in the 21st century: A changing need of process safety management for a changing industry. *Journal of Loss Prevention in the Process Industries*, *22*(2), 162–168. https://doi.org/10.1016/j.jlp.2008.11.005

Krause, U. (2016). Process Safety in Engineering Education - Pro’s and Con’s of Different pproaches. *AIDIC*, *48*, 871–876. https://doi.org/10.3303/CET1648146

Leveson, N. G., & Stephanopoulos, G. (2014). A system-theoretic, control-inspired view and approach to process safety. *AIChE Journal*, *60*(1), 2–14. https://doi.org/10.1002/aic.14278

Louvar, J. F. (2008). Improving the effectiveness of process safety management in small companies. *Process Safety Progress*, *27*(4), 280–283. https://doi.org/10.1002/prs.10267

Louvar, J. F. (2009). Safety and chemical engineering education-History and results. *Process Safety Progress*, *28*(2), 131–134. https://doi.org/10.1002/prs.10315

Louvar, J. F., & Hendershot, D. C. (2003). SACHE: 17 years of promoting teaching of safety to chemical engineering students. *Chemical Health and Safety*, *10*(5), 8–10. https://doi.org/10.1016/S1074-9098(03)00090-X

Louvar, J., & Hendershot, D. (2007). Education materials for universities and industry. *Process Safety Progress*, *26*(2), 85–89. https://doi.org/10.1002/prs.10196

Lundin, J., & Jönsson, R. (2002). Master of science in risk management and safety engineering, at Lund University, Sweden. *Journal of Loss Prevention in the Process Industries*, *15*(2), 111–117.

Mannan, M. S. (2012). Trevor Kletz's impact on process safety and a plea for good science – An academic and research perspective. *Process Safety and Environmental Protection*, *90*(5), 343–348. https://doi.org/10.1016/j.psep.2012.06.006

Mannan, M. S., Chen, H., Pittman, W. C., Hatanaka, L. C., Harding, B. Z., Boussouf, A., … Milke, J. A. (2015). Integration of process safety engineering and fire protection engineering for better safety performance. *Journal of Loss Prevention in the Process Industries*, *37*, 74–81. https://doi.org/10.1016/j.jlp.2015.06.013

Mannan, M. S., Qi, R., Prem, K. P., Ng, D., Rana, M. A., & Yun, G. (2012). Challenges and needs for process safety in the new millennium. *Process Safety and Environmental Protection*, *90*(2), 91–100. https://doi.org/10.1016/j.psep.2011.08.002

Mannan, S., Akgerman, A., Anthony, R., Darby, R., Eubank, P., & Hall, K. (1999). Integrating process safety into chE education and research. *Chemical Engineering Education*, 198–209.

McKay, G., Noakes, N., Chow, C. C. L., & Ko, E. (2011). Safety education for chemical engineering students in Hong Kong: Development of HAZOP Study teaching module. *Education for Chemical Engineers*, *6*(2), e31–e55. https://doi.org/10.1016/j.ece.2010.11.001

Meyer, T. (2015). Towards the implementation of a safety education program in a teaching and research institution. *Education for Chemical Engineers*. https://doi.org/10.1016/j.ece.2015.06.003

Moon, I., Goh, S., Chang, B., Jeong, I., & Kwon, H.-T. (1998). Safety Improvement by a Multimedia Operator Education System. *Computers Chemical Engineering, 22*, S531–S536. https://doi.org/PII:S OO98-1354(98)00097-O

Myers, P. M., Watson, B., & Watson, M. (2008). Effective training programs using instructional systems design and e-learning. *Process Safety Progress*, *27*(2), 131–138. https://doi.org/10.1002/prs.10245

Nazir, S., & Manca, D. (2015). How a plant simulator can improve industrial safety. *Process Safety Progress*, *34*(3), 237–243. https://doi.org/10.1002/prs.11714

Nesheim, T., & Gressgård, L. J. (2014). Knowledge sharing in a complex organization: Antecedents and safety effects. *Safety Science*, *62*, 28–36. https://doi.org/10.1016/j.ssci.2013.07.018

Norval, G., Pakalnis, V., & Pasteris, T. (2010). Teaching Occupational Health and Safety in Engineering Schools–Best Practices, Support, and Opportunities. *Proceedings of the Canadian Engineering Education Association*. Retrieved from http://queens.scholarsportal.info/ojs/index.php/PCEEA/article/viewFile/3160/3098

Olewski, T., Ahammad, M., Quraishy, S., Gan, N., Véchot, L. (2016). Building process safety culture at Texas A&M University at Qatar: A case study on experimental research. J. Loss Prev. Process Ind. 44, p. 642–652.

Osborn, L. (1999). Process Safety in Education. *Process Safety Progress*, *18*(4), W5.

Pasman, H. J., De Rademaeker, E., Suter, G., & Fabiano, B. (2014). A review of the past, present and future of the European loss prevention and safety promotion in the process industries. *Process Safety and Environmental Protection*, *92*(4), 280–291. https://doi.org/10.1016/j.psep.2014.03.007

Perrin, L., & Laurent, A. (2008). Current situation and future implementation of safety curricula for chemical engineering education in France. *Education for Chemical Engineers*, *3*(2), e84–e91. https://doi.org/10.1016/j.ece.2008.08.001

Pfeil, N., Jochum, C., Mitropetros, K., & Schmelzer. (2013). Keeping and Improving Process and Plant Safety Competence – What is Needed, What Should be Done? *AIDIC*, *31*, 373–378. https://doi.org/10.3303/ CET 1331063

Pintar, A. J. (1999). Teaching Chemical Process Safety: A Separate Course versus Integration into Existing Courses. *Age*, *4*, 1., p.479.1 - 479.6

Pitt, M. J. (2012). Teaching Safety in Chemical Engineering: What, How and Who? *Chemical Engineering & Technology*, *35*(8), 1341–1345. https://doi.org/10.1002/ceat.201200024

Rae, A. (2016). Tales of disaster: the role of accident storytelling in safety teaching. *Cognition, Technology & Work*, *18*(1), 1–10. https://doi.org/10.1007/s10111-015-0341-3

Reniers, G., & Amyotte, P. (2012). Prevention in the chemical and process industries: Future directions. *Journal of Loss Prevention in the Process Industries*, *25*(1), 227–231. https://doi.org/10.1016/j.jlp.2011.06.016

Reniers, G., & Khakzad, N. (2017). Revolutionizing Safety and Security in the Chemical and Process Industry: Applying the CHESS concept. *Journal of Integrated Security Science*, *1*, 2–15. https://doi.org/10.18757/jiss.2017.1.1547

Saleh, J. H., & Pendley, C. C. (2012). From learning from accidents to teaching about accident causation and prevention: Multidisciplinary education and safety literacy for all engineering students. *Reliability Engineering & System Safety*, *99*, 105–113. https://doi.org/10.1016/j.ress.2011.10.016

Schenk, L., & Antonsson, A.-B. (2015). Implementation of the chemicals regulation REACH – Exploring the impact on occupational health and safety management among Swedish downstream users. *Safety Science*, *80*, 233–242. https://doi.org/10.1016/j.ssci.2015.08.001

Schmidt, J. (2013). Process and Plant Safety – Research & Education Strategy to Keep Long Term Competences. *AIDIC*, *13*, 421–426. https://doi.org/10.3303/ CET 1331071

Schonbucher, A., Brenig, H. W., O. Klais, U. Hauptmanns, J. Schmidt, & H.U. Moritz. (2013). *Model and Curriculum "Process and Plant Safety."* Frankfurt, M: Dechema, p.1-16.

Shacham, M., Eizenberg, S., & Brauner, N. (2006). Combining HAZOP with dynamic simulation—Applications for safety education. *Journal of Loss Prevention in the Process Industries*, *19*(6), 754–761. https://doi.org/10.1016/j.jlp.2006.07.002

Shallcross, D. C. (2013). Safety education through case study presentations. *Education for Chemical Engineers*, *8*(1), e12–e30. https://doi.org/10.1016/j.ece.2012.10.002

Sol, V., Bollen, L. A., kooi, E., & Manuel, H. (2015). *Handreiking voor inspectie van Brzo- bedrijven* (Vol. 0048). RIVM.

Sonnemans, P. J. M., & Körvers, P. M. W. (2006). Accidents in the chemical industry: are they foreseeable? *Journal of Loss Prevention in the Process Industries*, *19*(1), 1–12. https://doi.org/10.1016/j.jlp.2005.03.008

Spicer, T. O., Willey, R. J., Crowl, D. A., & Smades, W. (2013). The safety and chemical engineering education committee-broadening the reach of chemical engineering process safety education. *Process Safety Progress*, *32*(2), 113–118. https://doi.org/10.1002/prs.11594

Sumption, S. (1999). Practical implementation of Seveso II directive in the UK. *Journal of Hazardous Materials*, *65*, 43–48.

Sutton, I. S. (2008). Use root cause analysis to understand and improve process safety culture. *Process Safety Progress*, *27*(4), 274–279. https://doi.org/10.1002/prs.10271

Swuste, P., & Reniers, G. (2016). Seveso inspections in the European low countries history, implementation, and effectiveness of the European Seveso directives in Belgium and the Netherlands. *Journal of Loss Prevention in the Process Industries*. https://doi.org/10.1016/j.jlp.2016.11.006

Taylor, M. A., Wirth, O., Olvina, M., & Alvero, A. M. (2016). Experimental analysis of using examples and non-examples in safety training. *Journal of Safety Research*, *59*, 97–104. https://doi.org/10.1016/j.jsr.2016.10.002

Véchot, L. N., Casson, V., & Olewski, T. (2014). Training future engineers to be committed to safety. *QScience Proceedings*, *2014*(3), 28. https://doi.org/10.5339/qproc.2014.wcee2013.28

Versluis, E., van Asselt, M., Fox, T., & Hommels, A. (2010). The EU Seveso regime in practice. *Journal of Hazardous Materials*, *184*(1–3), 627–631. https://doi.org/10.1016/j.jhazmat.2010.08.082

Vierendeels, G., Reniers, G., Van Nunen, K., Ponnet, K. (2018). An integrative conceptual framework for safety culture : The Egg Aggregated Model (TEAM) of safety culture, Safety science 103, p. 323-339

Wasileski, R. F. (2009). Spot the Hazard! A cultural extension of hazard identification training. *Process Safety Progress*, *28*(2), 200–206. https://doi.org/10.1002/prs.10280

Willey, R. J. (1999). SACHE Case Histories and Training Modwles. *Process Safety Progress*, *18*(4), 195–200.

Willey, R. J., Fogler, H. S., & Cutlip, M. B. (2010). The integration of process safety into a chemical reaction engineering course: Kinetic modeling of the T2 incident. *Process Safety Progress*, n/a-n/a. https://doi.org/10.1002/prs.10431

Wu, T.-C., Chang, S.-H., & Chen, D.-F. (2012). Developing a competency model for safety professionals: Correlations between competency and safety functions. *Journal of Safety Research*, *43*(5–6), 339–350. https://doi.org/10.1016/j.jsr.2012.10.009

Yamamoto, S. (2015). A Systematic Knowledge Education Approach for Safety-Critical System Development. *Procedia Computer Science*, *60*, 960–967. https://doi.org/10.1016/j.procs.2015.08.133

Young, C. W., & Hodges, K. J. (2012). Process safety management mentoring: Subjects to convey and the methods for conveying. *Process Safety Progress*, *31*(4), 350–354. https://doi.org/10.1002/prs.11529

Zaloom, V., & Ramachandran, P. (1996). A computer based training system for process safety management. *Computers & Industrial Engineering*, *31*(1), 511–514.