Graduates' Competency in Essential Process Safety Topics Required in the Downstream Industry

Sofri, Salwa; D.M., Reddy Prasad *+; Bin Azri, Mohammad Hazwan

Petroleum and Chemical Engineering Programme Area, Faculty of Engineering, Universiti Teknologi Brunei, Tungku Highway, Gadong BE1410, BRUNEI DARUSSALAM

ABSTRACT: *One of the strategies to mitigate industrial accidents is by developing competent engineers in process safety where graduates play an important role. This research investigates the essential process safety topics in the downstream industry and determines graduates' competency on these topics via a survey questionnaire. Responses from students, graduates, and employees with chemical engineering and process safety backgrounds are analyzed. Fire prevention and protection and management topics i.e., hazard and risk management and process safety management, are ranked with the highest importance. On the other hand, asset integrity and reliability, economics, process control, software, toxicology, and risk management are the top graduates' knowledge that dissatisfied the employees. The connection between these topics depicts students are unable to visualize the relations due to lack of industrial operation exposure thus they underestimate its importance for process safety in the industry. To mitigate this gap, direct learning with industry and personnel is commonly highlighted by participants.*

KEYWORDS: *Chemical engineering; Engineering Education; Risk management; Fire and explosion, Hazard management.*

INTRODUCTION

Process safety (PS) is defined as the prevention and mitigation of catastrophic accidents of the facility from loss of containment, fire and explosion, and toxic release. Chemical engineers play an important role in addressing this significant challenge in processing industries [1]. Lack of PS knowledge is one of the common causes of major accidents. Raising awareness of basic PS principles is remarked as one of the biggest challenges in engineering education [2]. Additionally, chemical PS systems have gradually evolved to become more complex. Therefore, i t is important to emphasize PS for undergraduate Chemical Engineering (CE) program and prepare the students to be involved in high-risk industries. Despite that, only a few CE faculty include PS education as a stand-alone course in their curriculum while others integrate PS education throughout their syllabus [3, 4]. This would possibly limit the PS knowledge of new CE graduates recruited to work in operations.

According to Wiley (2011),*"the elements of process safety competency (PSC) consist of 3 interrelated actions; continuously improving knowledge and competency, ensuring appropriate information is available to people who need to know it, and consistently applying what has already been learned"*. Notably, PS competence does not

*** *To whom correspondence should be addressed.*
+ *E-mail:*
1021-9986/2023/3/1057-1074 18/$/6.08

only apply to people's safety, but it also enhances organisational performance, sustainable development, and productivity while sustaining reliability in the process industry [6].

The aim of this research is also part of the mission to support Brunei 2035 vision's goals in accomplishing well-educated and skilled people to achieve sustainable energy for Brunei Darussalam's prosperity. This paper focuses on PS for CE as PS is the key element of a chemical engineer's work. This paper begins by considering PS education for the undergraduate CE programme. It then discusses the current PS gap in the university and industry world. Finally, it concludes by discussing the recommended solution to bridge the PS gaps.

In university, undergraduate CE students are taught the basic principles and applied principles of PS [7]. *Mkpat et al.*, (2018) verified that PS courses offered in most universities cover asset integrity and reliability, chemistry related courses, design, economics, fire and explosion studies, hazard identification and risk analysis, human factor, incident management, process control, process safety management (PSM), regulation, risk decision making, security, and software program [8]. From the author's previous research, 12 common topics in PS courses of top 300 universities' CE programme are established [4]. The common topics include human factor (14.7%), hazard management (14.0%), incident management (13.9%), risk management (12.6%), safety design (10.0%), fire and explosion (8.1%), safety legislation and standards (7.2%), sustainability (6.0%), process control (4.7%), economics (4.5%), toxicology (2.6%), and software (1.8%). The human factor was the most common PS topic among the top 300 universities while software program is the least. Topics on management such as hazard, risk and incident management are highly implemented as management is important to maintain a good PS system [4].

PS incompetence still exists in both the university and industry world. It was discovered from incident investigations that personnel are incompetent on communication skills on safety information, namely risks, hazards, and management, chemical reactivity hazards, control systems, etc. [2]. In regards with graduates' PS competency, there is limited information acquired. However, a statement identifies CE graduates as deficient in ethical and professional responsibilities, management and business, project management and sustainability [9]. Additionally, there is a gap in graduates' transferable skills. It was discovered that graduates are deficient with the skills highly ranked of importance for practicing engineers i.e., ability to identify, formulate and solve problems, work effectively in a team, and self-learning abilities [10]. Graduates' engineering and professional communication skills was also discovered to be lacking and has dissatisfied the employers [11]. Overall, employers rated business-oriented thinking the most unsatisfactory skill of graduates [10].

The remaining occurrence of these PS incompetency worldwide may indicate that students easily misinterpret engineering practice due to less industrial exposure. Implementing realistic exposure to real world complex problems will aid students' PS learning and understanding more [12]. Another explanation of graduates' PS incompetency is due to the shortfall and deficient industrial experienced lecturers who are able or willing to teach PS [6, 8]. Additionally, courses intended to acquaint students with accident causes and prevention is lacking [2]. Other insufficiently taught skills are identified to include communication, interdisciplinary approach, cultural diversity and ethical responsibilities [10].

Executing industry engagement for PS will aid to enhance students' accuracy of perceptions about working for the organisation. Therefore, it is important to keep in mind that establishing a strong alliance between university and industry is the key to developing competent engineering professionals.

This research paper aims to reduce graduates' PS knowledge gaps by determining employees' satisfaction level on graduates' competency on essential PS topics required in the industry.

EXPERIMENTAL SECTION

A quantitative method is applied to determine which common process safety topics acquired from author's previous research are required to prepare graduates for industrial employment and its best delivery approach. Google form viz., an online-based survey method, has been used to collect statistical data. The survey is voluntary and anonymous. To eliminate bias, the survey has been distributed to several universities and companies/industries locally and around the world through email and social networking sites (WhatsApp, Facebook, and LinkedIn) to receive students', graduates', and employees' points of view.

Gathering data from literature

Several literatures are gathered from the ScienceDirect database to aid this research. The literature comprises research associated with PS education and teaching, competency on PS and other related skills, and guidelines for improving the effectiveness of managing PS.

Deriving questions for survey

The questions are written to discover undergraduate students', graduates', and employees' perspectives on the common process safety topics and determine graduates' competency on these topics. The first six questions collected demographic information on the participants. These include whether the participant was a student, graduate, or employee as well as their gender, age, university name, degree programme, year of study/employment. As for graduates and employees, additional demographic questions include company names and occupations. In addition, the following questions covered knowledge level on PS, opinions on most important PS topics required in industry, suggestions on ideal delivery approach for the PS topics, and satisfaction on graduates' PS competency (only from employees' response).

The process safety topics used in this survey are acquired from the literature [8] and the results obtained from top 300 universities [4], as previously listed. Furthermore, the delivery approaches for process safety topics used in this survey are also referencing from literature viz. as stand-alone full course, integrated into all CE courses, case study, 2-4 min safety shares in every lecture, direct learning in fields, lecture by guest from industry and group project [13].

The additional comment section is included in this survey as part of the final question for participants' feedback regarding the research or the survey, etc. There was no reward or penalties associated with completing or not completing the survey.

Analysing the highest trend from overall participants

Data gathered from all the participants are analysed by observing the highest trend. The participants are expected to be from different degree and employment backgrounds. The results are gathered and analysed using both Microsoft Excel and Statistical Package for Social Sciences (SPSS) software. Different perspectives from students, graduates, and employees will be compared and examined. To really determine responses for this research, participants with chemical engineering backgrounds are the focal point. The results are also gathered and analysed using both Microsoft Excel and SPSS software where students, graduates and employees' perspectives are compared and examined.

RESULTS AND DISCUSSION

As PS is an integral part of chemical engineer's work, only participants with CE and PS backgrounds are analysed. PS backgrounds include participants with degree programs related to PS or participants with non-CE related degree programs but with occupations related with PS (see Appendix,

Table **1**, Table 2 and Table 3). There are 59 out of 84 participants, giving approximately 70% of participants representing relevant backgrounds. The low number of participants may be due to the voluntary nature of the survey. As a result, the findings may be biased to represent those motivated to participate in the survey.

Among the participants with relevant backgrounds, only 7% of recent graduates participated in the survey, while 49% of participants are undergraduate CE students, and 44% are experienced employees (Fig. 1). Less participation from recent graduates is probably due to their lack of confidence in their PS knowledge, which could demotivate them. In terms of their universities for an undergraduate degree programme, 28 attend/attended local (Brunei) universities and 31 attend/attended international universities i.e., Australia, India, Oman, United Kingdom, and Ukraine (Fig. 2).

According to survey data, only three of the fourth-year undergraduate CE students acknowledges to be very knowledgeable on PS (see Appendix, Table 4). Meanwhile, six third-year students are knowledgeable, six have neutral understanding, and one has little knowledge. Additionally, both the first and second-year students have either zero knowledge or little knowledge, which is apparent as PS education is usually employed at the third and fourth year of study. Regarding graduates' PS knowledge, only one graduate with two years of experience as a field offshore supervisor confidently claims that he is knowledgeable on PS, while the other graduate with two years of experience in operation has neutral PS knowledge (see Appendix, Table **5**). Two graduates (student and process engineer) with zero years

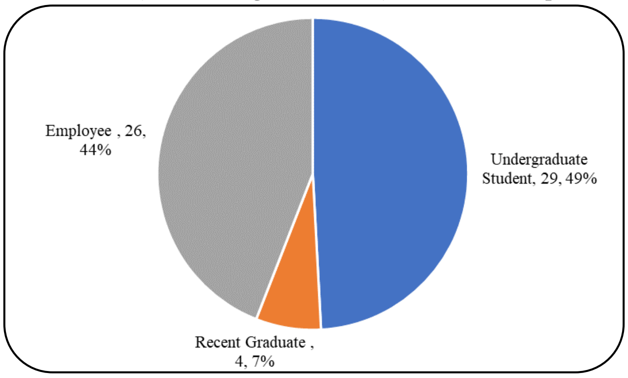

Fig. 1: Summary of CE and PS background participants for survey.

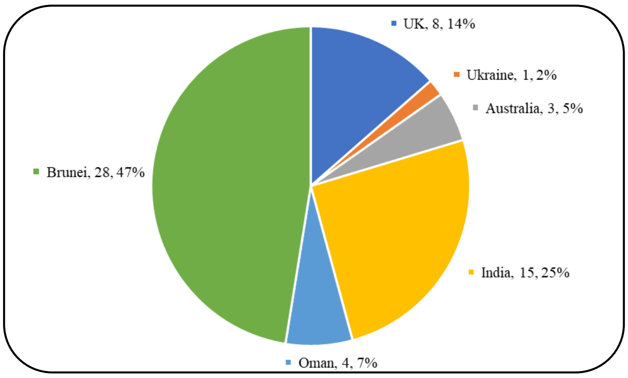

Fig. 2 Universities locality of survey participants.

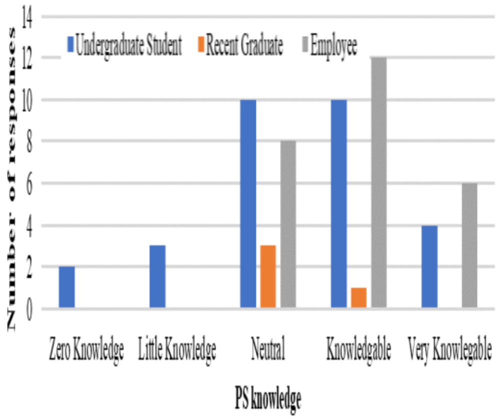

Fig. 3 Process safety knowledge of survey participants.

of working experience have neutral PS knowledge. Even though the sample size for graduates is relatively small, it is undeniably apparent that PS are experienced more in-depth in the industry area and their competency depends on seniority level. Multiple neutral PS knowledge among undergraduates and graduates indicates that there is still room for improvement in PS education in university. Most undergraduates declared to be competent on PS compared to graduates may imply that students tend to become less convinced with their PS knowledge after graduation as they have seen a broader view of PS outside the university world. As for the employee with neutral PS knowledge, it represents an engineer with 4-5 years of experience, two engineers working under management with more than 16 years of experience, an investment analyst, two process engineers with 4-5 and 6-10 years (BSc Chemistry background) of experiences, a professor with more than 16 years of experience, and senior process engineer with 11-15 years of experience. Most of the employees with neutral PS knowledge have undergraduate CE backgrounds. Understandably, the investment analyst declares unbiased PS knowledge as her work background is not related to PS. At the same time, the other employees opted to have neutral PS knowledge because they understood that PS is a vast topic. They also would likely sense that they still have much to learn regarding PS, particularly experiencing PS matter in person.

The essential PS topics required in the industry

As employed graduates and employees have experience with PS-related work, it is important to note their perspectives on the industry's important PS topics (Fig. 5 and Fig. 6). The analysed data indicates that hazard management, chemistry, risk management, fire and explosion studies, and PSM are ranked as the top five for critical PS topics in the industry by graduates and employees (Fig. 8). Whereas undergraduate students ranked hazard management, risk management, fire and explosion studies, toxicology, and PSM (Fig. 7). Overall, it is agreed by the participants that fire and explosion studies and management topics i.e., hazard management, risk management, and PSM are among the essential PS topics required in the industry. The high importance of these topics correlates with their high implementations in top 300 universities' CE curriculum except for PSM [4]. Although, the author's previous research shows that PSM is not among the common PS topics implemented in the undergraduate CE curriculum [4]. Only a few PSM topics integrated into other courses are observed [4]. Participants' perspectives on PS topics proposed by *Shallcross* (2014) are also determined and summarised that hazard management, risk management, and fire prevention and protection are also rated as the most important (see Appendix, Table **7**).

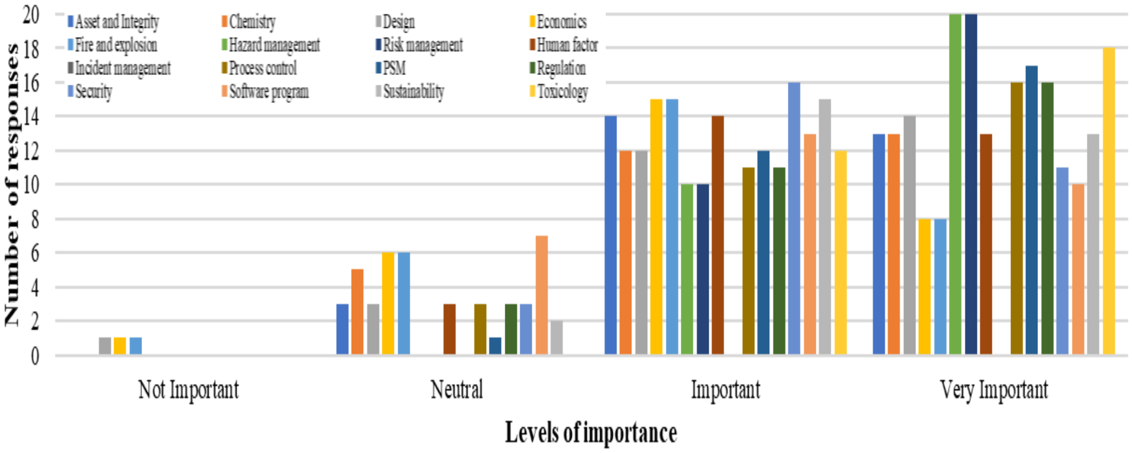

Fig. 4: ***The levels of importance for PS topics required in the industry from undergraduate students' perspectives.***

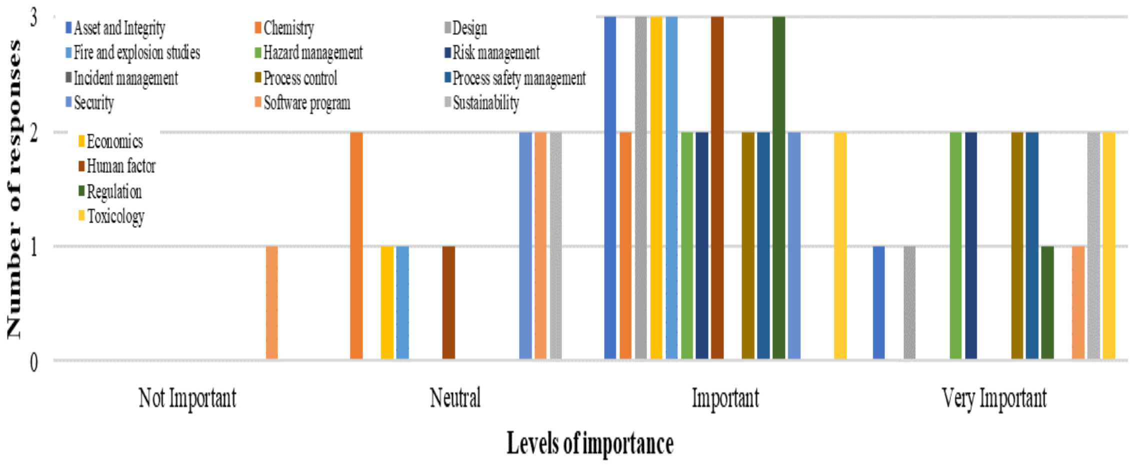

Fig. 5: ***The levels of importance for PS topics required in industry from graduates' perspectives.***

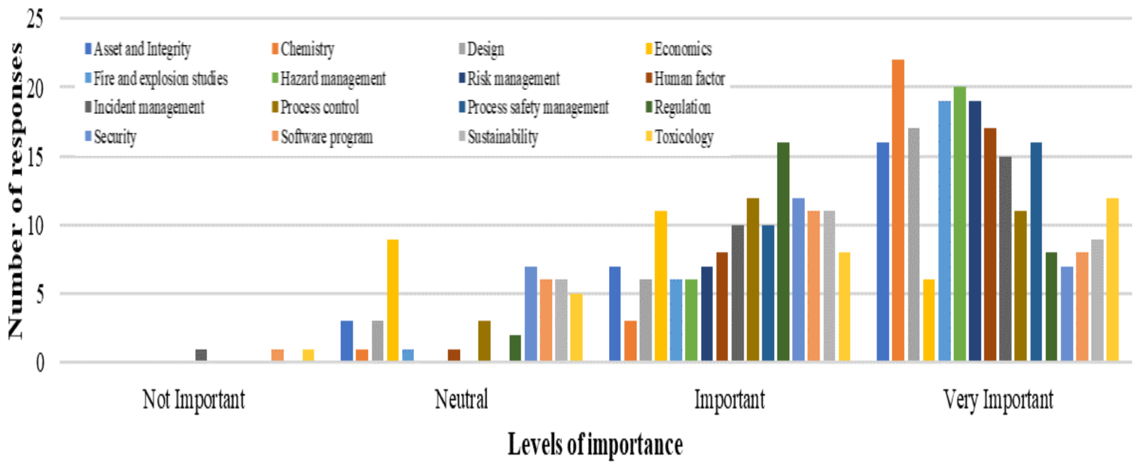

Fig. 6 The levels of importance for PS topics required in industry from employees' perspectives.

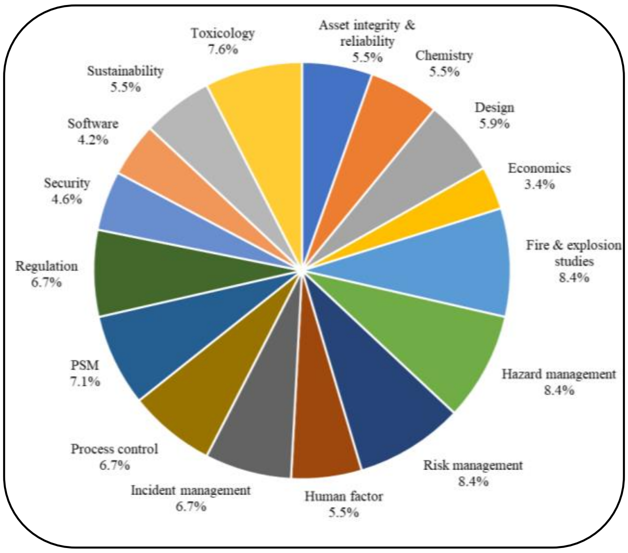

Fig. 7: Summary of undergraduate students' perspectives on critical PS topics required in the industry.

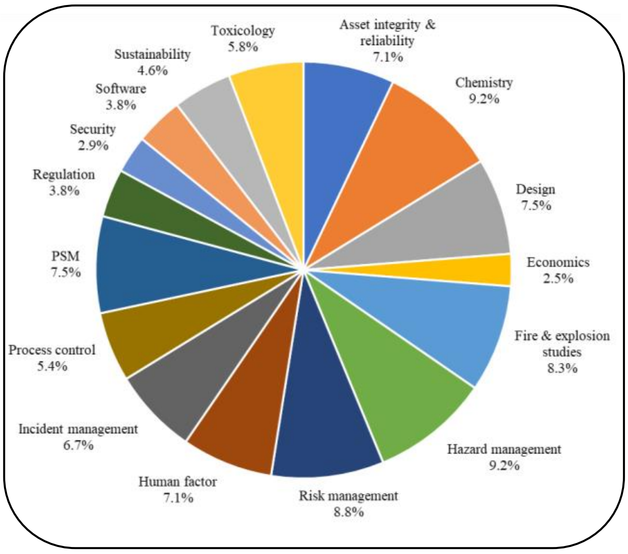

Fig. 8: Summary of graduates' and employees' perspectives on critical PS topics required in the industry.

have also supplied feedback on other important PS topics required in the industry (see Appendix,

Table **8**). It can again be agreed that management topics, especially hazard and risk management, are the most important PS topic to be exposed to and be aware by students in the industry. And again, this is because management is the key to maintain a sound PS system.

Most of the topics mentioned in

Table **8** (see Appendix) have already been implemented in the undergraduate CE curriculum but not SIMOPs, handling heavy metals, usage and maintenance of Personal Protective Equipment (PPE), and digitalisation. Instead, currently, students can learn these topics via industry exposure. Digitalisation is acknowledged by the participant likely due to the implementation of Industry 4.0 to enhance decision-making and performance in the industry. Besides its goal of improving business outcomes, digitalisation also plays a significant role in developing and managing engineered systems [14]. It was emphasised that the employment of both digitalisation and industry 4.0 in process industries could assist the development of PS thru mitigating incidents caused by inadequate mechanical integrity and maintenance practices [14]. Even so, the author's previous research shows that digitalisation has not been implemented as part of PS education [4].

Both graduates and employees have also expressed that ethics is an important topic, presumably because they are convinced that there is an ethical competency gap for graduates in the industry. Ethical conduct is one of the skills desired and critical for safety professional practice by organisations [15]. Despite its imperativeness in industry, it has been mentioned previously that internationally CE graduates are deficient in ethical conduct [9] due to insufficiently taught in university [10].

Employees' satisfaction level on graduates' PS competency

To determine graduates' PS knowledge gaps, employees' satisfaction levels on graduates' PS competency are analysed (Fig. 9). The finding shows that employees are mostly dissatisfied with graduates' knowledge on asset integrity and reliability, economics, process control, software, toxicology, and risk management. In addition, a study pointed out that graduates are deficient in ethics, professional responsibilities, and sustainability topics [9]. Findings show that employees are dissatisfied with graduates' knowledge of human factors and sustainability, but they are not among the top six topics (Fig. 9).

Asset Integrity and Reliability

Over time, risks build up as plants age due to equipment damage mechanisms. Equipment or material degradation caused by mechanical, chemical, physical, or other processes eventually leads to loss of containment if not properly managed [16]. Equipment deterioration and

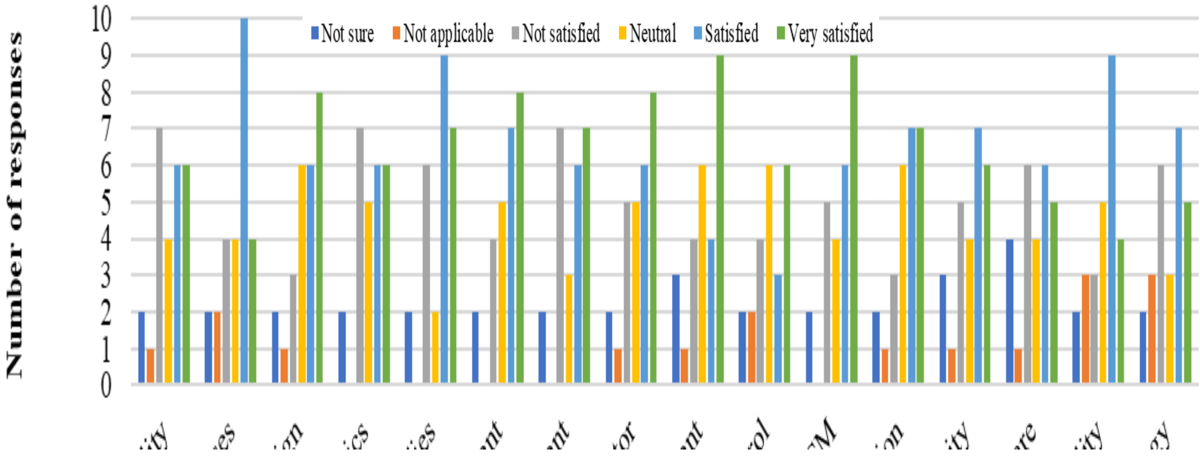

Fig. 9: Employees' satisfaction level on graduates' PS competency at their workplace.

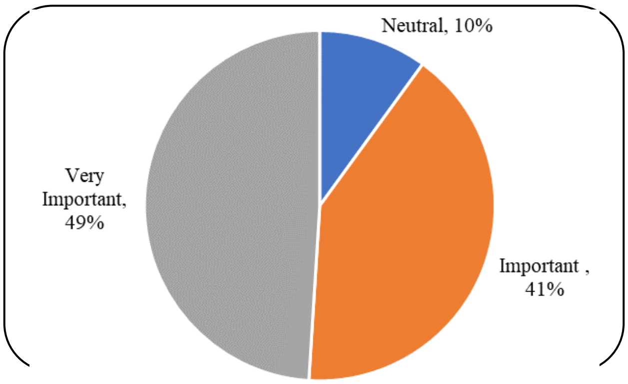

Fig. 10: Participant's perspectives on the importance of asset integrity and reliability for PS in the industry.

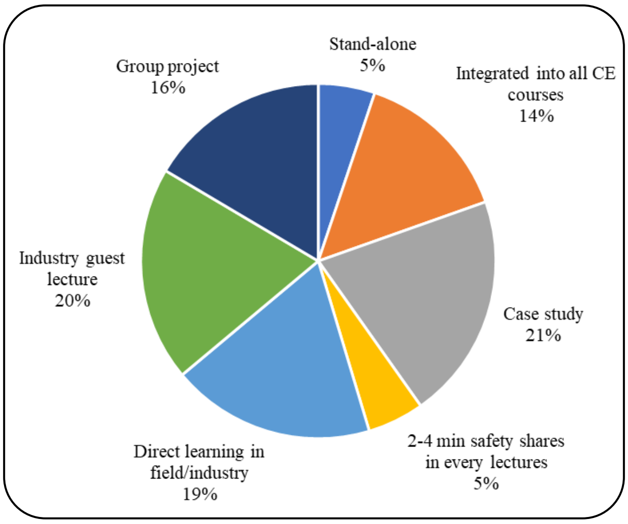

Fig. 11: Suggested delivery approach for asset integrity and reliability by survey participants.

outdated technology has played a role in some incidents [16]. Moreover, it was identified that inspecting and maintaining equipment periodically to ensure adequate equipment reliability is deficient and has caused ten historical incidents [17]. Hence, the importance of asset integrity and reliability topic was expressed by survey participants (Fig.). However, asset integrity and reliability are among the highest PS topics dissatisfied by the employees (Fig. 9). Graduates' insufficient exposure to the industry, i.e., witnessing asset condition or being made aware of its importance during their degree programme is likely to contribute to this.

It was considerably suggested to teach CE students on asset integrity and reliability by case study, invite guests from industry to give a lecture, and direct learning in the industry (Fig.). It depicts that asset integrity and reliability should be taught via stimulating students' awareness and understanding on the importance of this topic in the industry.

Economics

Economics is a general topic for the engineering programme and its awareness is valuable for PS, particularly for applying optimal safety strategy. Economics analysis aids the chemical industry in deciding strategies for safety investments to prevent and minimise costs losses, prolong profitability, and provide sustainability [18].

Despite this, graduates' economics skill was found to have the same dissatisfaction level as asset integrity and reliability topic. The high dissatisfaction level of economic competency is probably due to the inadequate implementation of economics in PS education for undergraduate CE [4]. From author' previous research, it was examined that only 76 (4.5%) economics implemented for PS education and are mostly (61%) incorporated in a group project (particularly design project), 24% integrated into other PS courses, and 15% implemented as a stand-alone course [4]. Economics perceived as an insignificant PS topic required in the industry compared to other PS topics is possibly one of the circumstances for these findings as well (Fig. 7, Fig. 8 and Fig.).

Students are taught simple economic analysis in the undergraduate CE curriculum. They learned to estimate and consider the design and equipment by implementing economic tools and methods. In conjunction with that, they also learned capital investment and discounted cash flows [4].

Survey participants highly suggested that survey participants teach economics by integrating the topic with a case study (Fig. 13), different from the author's previous research [4]. It is believed that through a case study, students can be made aware of the risk of economic losses i.e., assets and production derived from incidents.

Process control

Despite the importance of process control in industry, it is one of the PS topics that has dissatisfied the employees. Process control and safeguarding equipment utilised in the industry has become more complex, increasing the risk of defective equipment [19]. Therefore, knowledge in proper management of process control is necessary. In spite of that, students' learning experience on process control, i.e., operability, equipment, and procedures, has a deficit, diminishing their imaginative ability and leading to poor decision-making skills [20].

Survey participants have suggested to implement process control as a stand-alone course (Fig.). However, the author previously found that only 5%of process control are taught as a stand-alone course while 64% are integrated into other CE courses, and 31% are integrated part of a group project [4]. It was mentioned to integrate it with simulation software [20]. It will motivate the students to learn and make learning much easier [20].

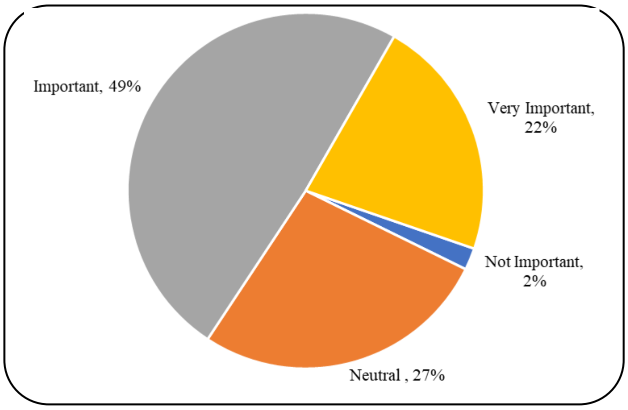

Fig. 12: Participant's perspectives on the importance of economics for PS in industry.

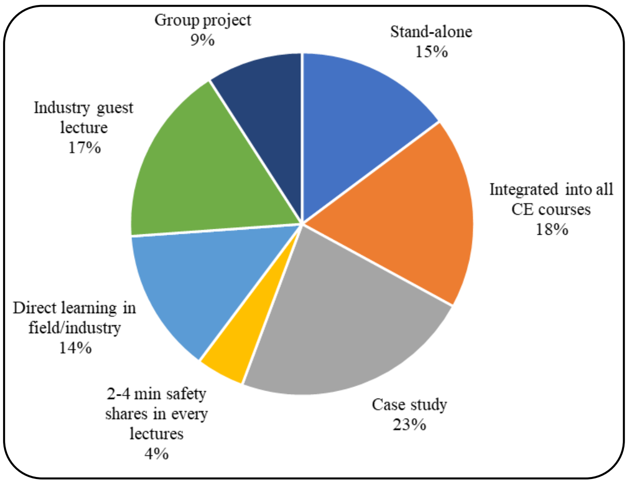

Fig. 13: Suggested delivery approach for economics by survey participants.

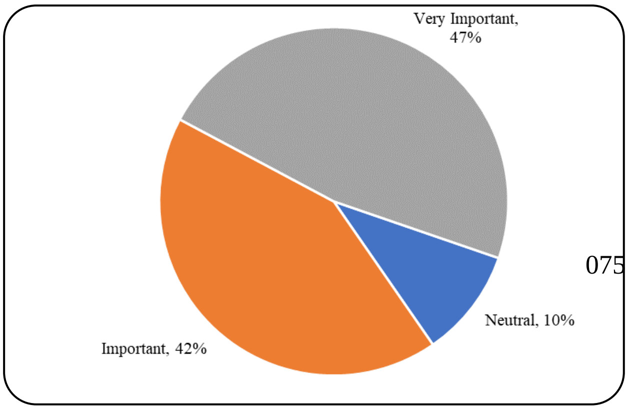

Fig. 14: Participant's perspectives on the importance of process control for PS in industry.

Software

Software integration is part of Industry 4.0. The software program is utilised mainly to support decision-makings i.e., design, hazard analysis, process control, etc. [14]. The teaching of software programs is considered one of the less prioritised topics in the undergraduate CE curriculum [8]. The implementation of software program for undergraduate CE's PS education in top 300 universities comprised only 1.8% [4]. Students are taught using software programs in university via practical work, i.e., laboratory work, individual or group projects, etc [4]. The usage of simulation software for PS education is favoured in enhancing students' understanding of basic engineering concepts, problem solving skills, design, etc. [21]. Nevertheless, there is a gap in CE graduates' competency on software program. This is likely due to differ software used in university and industry [10]. Another possible reason is the limited adequate educator to teach these software programs.

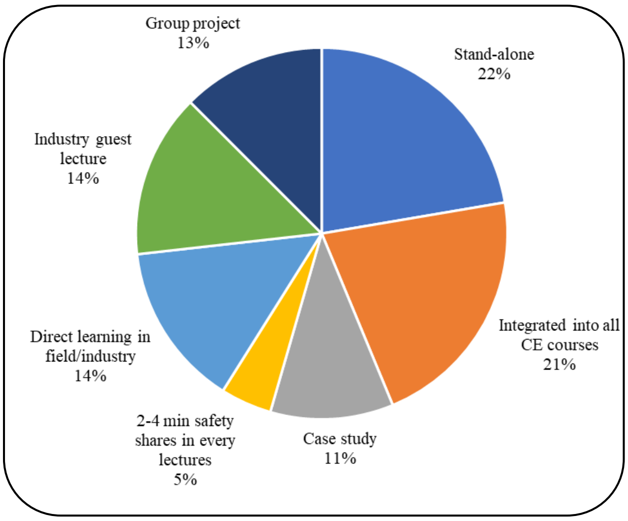

Fig. 15: Suggested delivery approach for process control by survey participants.

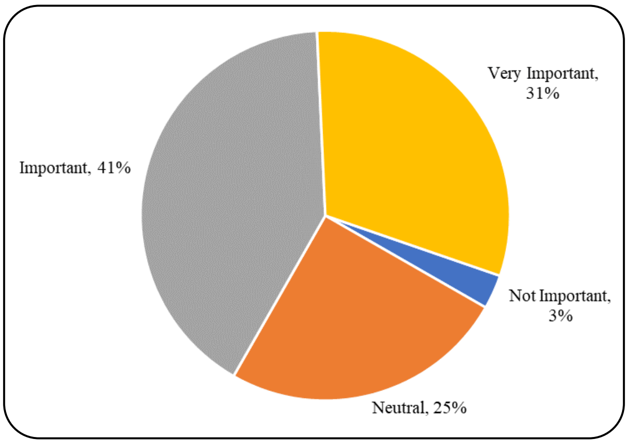

Fig. 16: Participant's perspectives on the importance of software program for PS in industry.

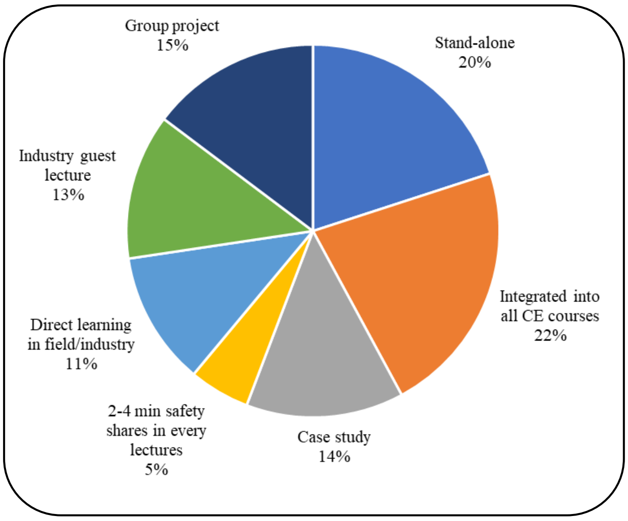

Fig. 17: Suggested delivery approach for software program by survey participants.

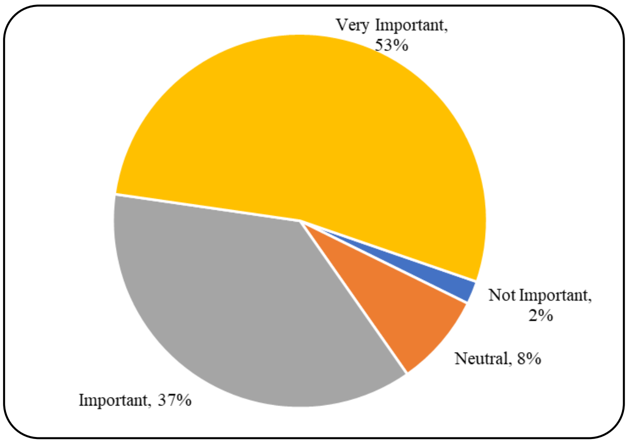

Fig. 18: Participant's perspectives on the importance of toxicology for PS in industry.

To mitigate the gap, it was suggested by the survey participants to teach software mostly thru integration into all CE courses and followed by as stand-alone course and group project (Fig.). However, it is found that only 7% of software programs have been taught as stand-alone courses while 43% integrated into all CE courses, and 47% in group project [4]. This implies a need for an interface between university and industry to train students on the required software program in the industry.

Toxicology

Knowledge of characterising toxic materials and ways to control and mitigate its hazards is important for PS viz. to prevent and mitigate the widespread toxicity caused by incidents [2]. Competent in toxicology is significant for achieving effective inherent safety. Accordingly, toxicology is included for undergraduate CE's PS education [4]. However, its implementation is scarce [4], which raises employees' dissatisfaction with graduates' competency on this topic.

To mitigate this toxicology knowledge gap, it is suggested to involve case study (Fig.). Through past incidents, students would be more aware on the harmful consequences of toxic release to the environment. Example of case study involving toxic release include the Three Mile Island (1979), Chernobyl (1987), Longford (1998), etc. [22].

Risk management

Risk management is one of the knowledge that all engineers require as the success of an engineering project depends on it [2]. Moreover, as mentioned before, all participants rated risk management as highly important in the industry, which is expected as improper management of risk can cause incidents that may lead to human, environmental, assets, and production losses. And yet, graduates' knowledge of risk management is one of the top six PS topics that has dissatisfied the employees even though it is highly implemented in the CE curriculum [4]. This finding is in accordance with a study indicating that students are deficient in the awareness of proper handling, storage and disposal of hazardous materials while operating in the laboratory[23].

The participants suggested that they teach risk management by integrating it into all CE courses, implementing with case studies, and via lecture by guest from industry (Fig.). According to a study, a university has successfully improved students' risk assessment knowledge [24]. They have introduced the concepts of risk assessment and safety barriers in the first year of CE programme. Students are trained to solve simpler problems in the second and third year, which gradually increase to more complex scenarios whilst applying risk assessment exercises.

Overall dissatisfactory on graduates' skills

As there are six top-rated graduates' skills that has dissatisfied the employees, the connection between these topics are investigated to identify the factor to what may causes it. Asset management is driven by technical and

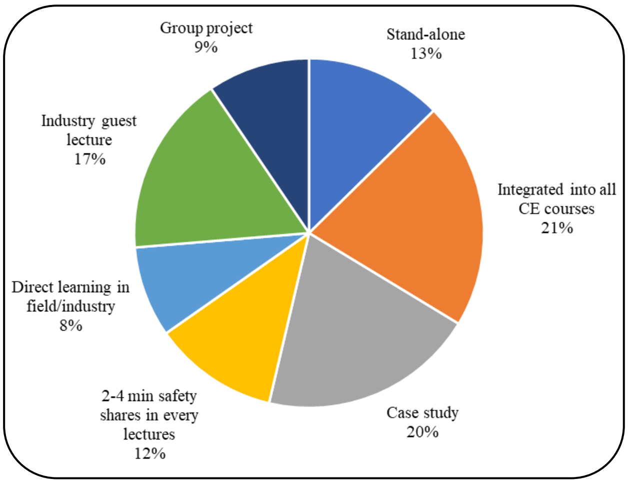

Fig. 19: Suggested delivery approach for toxicology by survey participants.

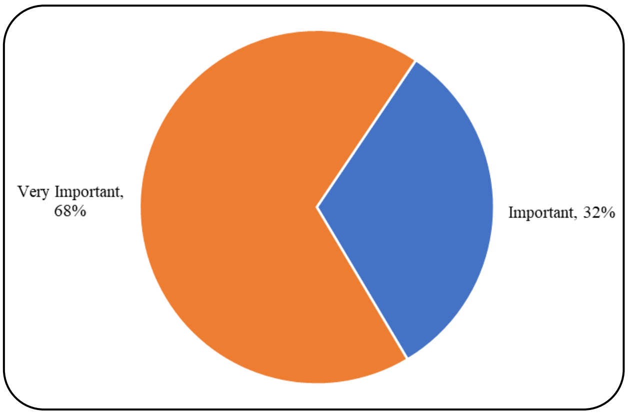

Fig. 20: Participant's perspectives on the importance of risk management for PS in industry.

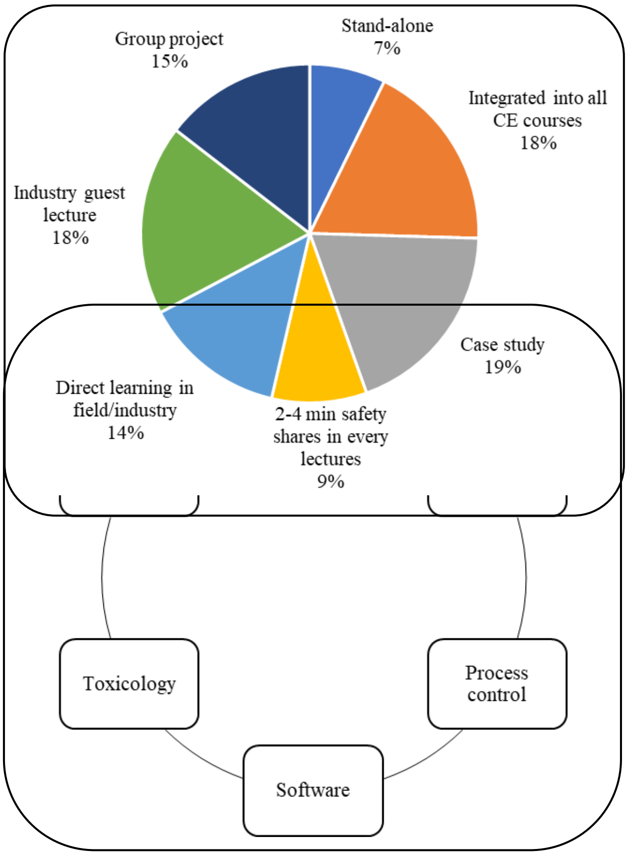

Fig. 10: Top PS topics that has dissatisfied the employees.

economics and the financial side of management [25]. The key elements for asset integrity implementation include corporate business and financial modelling (economics), risk assessment, prioritization, and risk-based inspection (risk management), and software tools [25]. Loss of structural integrity has led to widespread toxic release to the environment [3]. Proper risk management is vital to mitigate or reduce the likelihood of incidents that may lead to asset losses and toxic release. Process control, either hand-operated and/or computerised, is utilised to manage risk viz. It ensures the process variability is controlled within their respective boundaries. There are three aspects of risk management importance i.e., ethics, legal, and financial [2]. In safety economics, risk management is applied for the risk-based safety optimization approach [25]. Software also act as a tool to support decision-making in performing safety economics [18]. Computerised systems involving software programs for PS purposes have already been widely used in some advanced process industries [14]. The gap in graduates' competency in these topics can imply that is caused by the lack of industrial

Fig. 21: Suggested delivery approach for risk management by survey participants.

exposure implemented for undergraduate PS education. Due to the lack of industrial exposure, the students may be unable to visualise the relations of these three topics and hence underestimate their importance for PS.

Suggested delivery approach for bridging PS gaps

Several graduates and employees have suggested other ideal delivery approaches for PS education in the undergraduate CE programme. However, the delivery approaches they have suggested in the comments section involve industry contributions such as industrial internship, site visits, industry conferences, invite industry employees to give a lecture, and workshops. Moreover, most of the proposed delivery approaches for PS topics also concern the industry's involvements, i.e., direct learning in the field/industry and lectures by guests from industry (Fig.).

These suggested delivery approaches clarify that they consider the traditional learning method alone not enough for PS education as it would restrict graduates' skills. It is well-known of the importance of maintaining industry's involvement in student's PS education. The opportunity to learn vicariously from experienced personnel, such as witnessing real-life practical work on site is recognised to enhance students' awareness of safety that is difficult to be taught in university classrooms. One of the survey participants expressed that shadowing experienced supervisors during internships is beneficial for enhancing students' real-life work experience.

Apart from implementing a face-to-face delivery approach, utilising a virtual method is deemed to give a positive outcome for PS education as it can expose students to industrial life. Especially amid Industry 4.0 coming to maturity, it would be propitious to exploit digital technology by combining real and virtual worlds. Education 4.0 for teaching PS. This could be a suggestion for future research.

Limitation of study

There may be some possible limitations in this study. The primary limitation is the small sample size to measure the results of the research. Despite sending the survey to various universities and companies, most of the receivers are not motivated enough to participate in this study. The small sample size particularly representative from graduates has made it difficult to draw valid conclusions. It has impacted the approach to compare graduates' statements regarding their PS knowledge with the findings acquired from employees' satisfaction level with graduates' PS competency. An adequate number of participants could have provided more generalise research findings. The second limitation is the lack of research studies concerning graduates' PS competency, making it difficult to make comparisons with the findings. Both insufficient sample size and inadequate information gathered from the literature have complicated the assessment of graduates' PS knowledge gaps. These limitations do not entirely disrupt the study as results can still be acquired. On the contrary, these limitations provide the opportunity to encourage further development in this area of study.

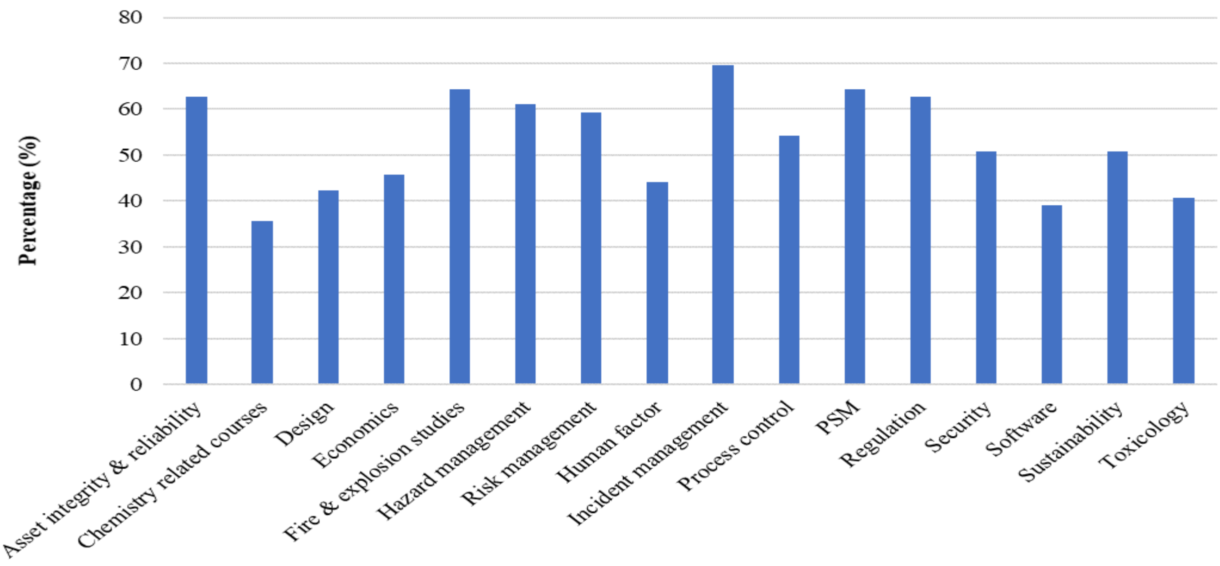

Fig. 23: Summary of participants' perspectives of involving industry's contributions for PS education.

CONCLUSIONS

Among the most common PS topics implemented in undergraduate CE curriculum, fire and explosion studies and management topics i.e., hazard and risk management, and PSM are the essential PS topics required in the industry. Graduates' competency on these important PS topics is desired considering management is the key to maintaining a good PS system. To determine graduates' PS competency, employees are dissatisfied with graduates' knowledge of asset integrity and reliability, economics, process control, software program, toxicology, and risk management. This PS competency gap is concluded to be the results of students' lack of exposure to the practical aspects of how the real-life plants or assets are being operated. It is crucial to mitigate these gaps as these PS topics are deemed to be paramount in the industry as it would affect the development and safety of organisations, workers, public, and the environment if not properly managed. To show how PS is put into industrial practice and demonstrate the importance of PS to the design and operation of a chemical plant, several participants have suggested several delivery approaches. It involves implementing workshops, lectures by guests from industry, site visits, industrial internship, etc. to their curriculum. Most of the methods suggested involving a contribution from the industry world. However, these delivery methods are sometimes ineffective and insufficient; hence, utilising digitalisation and virtual technology needs to be considered by the university to bridge graduates' PS competency gap. The limitations of this study offer the opportunity for further research in this area. Assessing undergraduates' and graduates' competency on the PS topics that have dissatisfied the employees could advance the study more and provide benefits for the chemical industry's future.

Abbreviations

CE	Chemical engineering
PPE	Personal protective equipment
PS	Process safety
PSM	Process safety management
SIMOP	Simultaneous operation identification and control
SPSS	Statistical Package for Social Sciences
VR	Virtual reality

Received : Mar.. 14, 2022 ; Accepted : Jun. 13, 2022

REFERENCES

[1] Hassall M.E., Lant P., Cameron I.T., Student Perspectives on Integrating Industrial Practice in Risk and Process Safety Education, *Educ. Chem. Eng.*, **32**: 59–71 (2020).
doi: 10.1016/j.ece.2020.04.002.

[2] Amaya-Gómez R., Dumar V., Sánchez-Silva M., Romero R., Arbeláez C., Muñoz F., Process Safety Part of the Engineering Education DNA, *Educ. Chem. Eng.*, 1–11 (2019).
doi: 10.1016/j.ece.2019.02.001.

[3] Behie S.W., Halim S.Z., Efaw B., O'Connor T.M., Quddus N., Guidance to Improve the Effectiveness of Process Safety Management Systems in Operating Facilities, *J. Loss Prev. Process Ind.*, **68(August):** 104257 (2020).
doi: 10.1016/j.jlp.2020.104257.

[4] Sofri S., Timbang A., Azri H., R. P. D. M, "Analysis of Undergraduate Chemical Engineering Curriculum to Improve Process Safety Competency," (2021). [Unpublished manuscript].

[5] Wiley, "Guidelines for Auditing Process Safety Management Systems - CCPS (Center for Chemical Process Safety)" - Google Books, Center for Chemical Process Safety of the American Institute of Chemical Engineers and John Wiley & Sons, Inc., (2011).

[6] Perrin L., Gabas N., Corriou J.P., Laurent A., Promoting Safety Teaching: An Essential Requirement for the Chemical Engineering Education in the French Universities, *J. Loss Prev. Process Ind.*, **54(March)**: 190–195 (2018).
doi: 10.1016/j.jlp.2018.03.017.

[7] Benintendi R., The Bridge Link between University And Industry: A Key Factor for Achieving High Performance in Process Safety, *Educ. Chem. Eng.*, **15**: 23–32 (2016).
doi: 10.1016/j.ece.2016.02.002.

[8] Mkpat E., Reniers G., Cozzani V., Process Safety Education: A Literature Review, *J. Loss Prev. Process Ind.*, **54(October 2017)**: 18–27 (2018).
doi: 10.1016/j.jlp.2018.02.003.

[9] Lenihan S., Foley R., Carey W.A., Duffy N.B., Developing Engineering Competencies in Industry for Chemical Engineering Undergraduates Through the Integration of Professional Work Placement and Engineering Research Project, *Educ. Chem. Eng.*, **32**: 82–94 (2020),.
doi: 10.1016/j.ece.2020.05.002.

[10] Fletcher A.J., Sharif A.W.A., Haw M.D., Using the Perceptions of Chemical Engineering Students and Graduates to Develop Employability Skills, *Educ. Chem. Eng.*, **18**: 11–25 (2017).
doi: 10.1016/j.ece.2016.07.001.

[11] Yong E., Ashman P.J., Integration of the Structured Development of Communication Skills within a Chemical Engineering Curriculum at the University of Adelaide, *Educ. Chem. Eng.*, **27**: 20–27 (2019).
doi: 10.1016/j.ece.2018.12.002.

[12] Wolff K.E., Dorfling C., Akdogan G., Shifting Disciplinary Perspectives and Perceptions of Chemical Engineering Work in the 21st Century, *Educ. Chem. Eng.*, **24**: 43–51 (2018).
doi: 10.1016/j.ece.2018.06.005.

[13] Zeng A., Zeng A., Cultivating a Safety Mindset in Chemical Engineering Students: Design of a Training Module," *Educ. Chem. Eng.*, **20**: 32–40 (2017).
doi: 10.1016/j.ece.2017.07.004.

[14] Lee J., Cameron I., Hassall M., Improving Process Safety: What Roles For Digitalization and Industry 4.0?, *Process Saf. Environ. Prot.*, **132**: 325–339 (2019).
doi: 10.1016/j.psep.2019.10.021.

[15] Madigan C., Johnstone K., Cook M., Brandon J., Do Student Internships Build Capability? – What

OHS Graduates Really Think, *Saf. Sci.*, **111(September 2018)**: 102–110 (2019).
doi: 10.1016/j.ssci.2018.10.003.

[16] Baybutt P., Insights Into Process Safety Incidents from an Analysis of CSB Investigations, *J. Loss Prev. Process Ind.*, **43**: 537–548 (2016).
doi: 10.1016/j.jlp.2016.07.002.

[17] Zhao J., Suikkanen J., Wood M., Lessons Learned for Process Safety Management in China, *J. Loss Prev. Process Ind.*, **29(1)**: 170–176, (2014).
doi: 10.1016/j.jlp.2014.02.010.

[18] Chen C., Reniers G., Khakzad N., Yang M., Operational Safety Economics: Foundations, Current Approaches and Paths for Future Research, *Saf. Sci.*, **141(November 2020)**: 105326 (2021).
doi: 10.1016/j.ssci.2021.105326.

[19] MKO Process Safety Center, "Process Safety Research Agenda for the 21st Century". (2011).

[20] Moodley K., Improvement of the Learning and Assessment of the Practical Component of a Process Dynamics and Control Course for Fourth Year Chemical Engineering Students, *Educ. Chem. Eng.*, **31**: 1–10 (2020).
doi: 10.1016/j.ece.2020.02.002.

[21] Nolan D.P., Anderson E.T., Benefits of Integrated PSM/SMS/SHE and OE Programs, *Appl. Oper. Excell. Oil, Gas, Process Ind.*, 87–114 (2015).
doi: 10.1016/b978-0-12-802788-2.00004-x.

[22] Eljack F., M.K. Kazi, Process Safety And Abnormal Situation Management, *Curr. Opin. Chem. Eng.*, **14**: 35–41 (2016).
doi: 10.1016/j.coche.2016.07.004.

[23] Artdej R., Investigating Undergraduate Students' Scientific Understanding of Laboratory Safety, *Procedia - Social and Behavioral Sciences* **46**: 5058–5062 (2012).
doi: 10.1016/j.sbspro.2012.06.385.

[24] Gyenes Z., Improve Process Safety in Undergraduate Education, *Chem. Eng. Trans.*, **77(March)**: 397–402 (2019).
doi: 10.3303/CET1977067.

[25] Singh R., Asset Integrity Management and Other Concepts of Asset Reliability, *Pipeline Integr. Handb.*, 271–288 (2017).
doi: 10.1016/b978-0-12-813045-2.00018-1.

APPENDIX

Table 1: Summary of participated undergraduate students' degree programme.

		Current year of study			
		1st year	2nd year	3rd year	4th year
Programme	BEng Chemical Engineering	2	7	12	6
	B-Tech Chemical Engineering	0	0	1	0
	Chemical and Process Engineering	0	1	0	0

Table 2: Summary of participated recent graduates' occupation and educational background.

		Undergraduate degree programme for recent graduates
		BEng Chemical Engineering
Occupation	Field Offshore Supervisor	1
	Operation	1
	Process Engineer	1
	Student	1

Table 3: Summary of participated employees' occupation and educational background.

		Undergraduate degree programme for employees					
		BEng Chemical Engineering	B. Tech Chemical Engineering	BEng Mechanical Engineering	BSc Chemistry	Foundation. in Petroleum Engineering	MEng Chemical Engineering
Occupation	Assistant Lecturer	1	0	0	0	0	0
	Assistant Professor	3	0	0	0	0	0
	Associate Professor	1	0	0	0	0	0
	Business Excellence Manager	1	0	0	0	0	0
	Chemical Engineer	1	0	0	0	0	0

Engineer	1	0	0	0	0	0
Engineer, Management	2	0	0	0	0	0
Faculty	1	0	0	0	0	0
Head of Process and Technical Safety	0	1	0	0	0	0
Investment Analyst	1	0	0	0	0	0
Process Engineer	1	0	1	1	0	1
Production Operator	0	0	0	0	2	0
Professor	5	1	0	0	0	0
Senior Process Engineer	1	0	0	0	0	0

Table 4: Summary of undergraduate students' PS knowledge.

				Process Safety knowledge				
				Zero knowledge	Little knowledge	Neutral understanding	Knowledgeable	Very knowledgeable
Programme	BEng Chemical Engineering	Current year of study	1st year	1	1	0	0	0
			2nd year	1	1	3	2	0
			3rd year	0	0	6	6	0
			4th year	0	0	1	2	3
	B-Tech Chemical Engineering		1st year	0	0	0	0	0
			2nd year	0	0	0	0	0
			3rd year	0	1	0	0	0
			4th year	0	0	0	0	0
	Chemical and Process Engineering		1st year	0	0	0	0	0
			2nd year	0	0	1	0	0
			3rd year	0	0	0	0	0
			4th year	0	0	0	0	0

Table 5: Summary of recent graduates' PS knowledge.

		Years of employment				Process Safety knowledge				
		0 year	1 year	2 years	3 years	Zero knowledge	Little knowledge	Neutral understanding	Knowledgeable	Very knowledgeable
Occupation	Field Offshore Supervisor	0	0	1	0	0	0	0	1	0
	Operation	0	0	1	0	0	0	1	0	0
	Process Engineer	1	0	0	0	0	0	1	0	0
	Student	1	0	0	0	0	0	1	0	0

Table 6: Summary of employees' PS knowledge.

		Years of employment				Process Safety knowledge				
		4-5 years	6-10 years	11-15 years	>16 years	Zero knowledge	Little knowledge	Neutral understanding	Knowledgeable	Very knowledgeable
Occupation	Assistant Lecturer	1	0	0	0	0	0	0	1	0
	Assistant Professor	0	0	2	1	0	0	0	1	2
	Associate Professor	0	0	0	1	0	0	0	1	0
	Business Excellence Manager	0	0	0	1	0	0	0	0	1
	Chemical Engineer	0	1	0	0	0	0	0	1	0
	Engineer	1	0	0	0	0	0	1	0	0
	Engineer, Management	0	0	0	2	0	0	2	0	0
	Faculty	0	1	0	0	0	0	0	0	1
	Head of Process and Technical Safety	0	0	1	0	0	0	0	1	0
	Investment Analyst	1	0	0	0	0	0	1	0	0
	Process Engineer	1	3	0	0	0	0	2	2	0
	Production Operator	0	0	2	0	0	0	0	2	0
	Professor	3	0	2	1	0	0	1	3	2
	Senior Process Engineer	0	0	1	0	0	0	1	0	0

Table 7: Summary of participants' perspectives on additional important PS topics.

Additional PS topics proposed by Shallcross (2014)	Yes (Freq.)	Yes (%)	No (Freq.)	No (%)
Able to find information on safety & health rules, regulations, and standards	46	78.0	13	22.0
Employer and employee rights and responsibilities under the law where they are practicing	35	59.3	24	40.7
Record keeping and reporting requirements	31	52.5	28	47.5
Fire prevention and protection	51	86.4	8	13.6

Hazards of dealing with chemicals, toxic material, and hazardous wastes	51	86.4	8	13.6
Biomedical hazards	34	57.6	25	42.4
Permit-to-work systems relating to procedures including confined space entry	31	52.5	28	47.5
Safety management systems	41	69.5	18	30.5
Responding to site emergencies such as hazardous material emergencies	34	57.6	25	42.4
Environmental protection requirements	36	61.0	23	39.0
Hazards associated with maintenance procedures and recovering from process upsets	37	62.7	22	37.3
Hazard identification and strategies for minimisation of risk	49	83.1	10	16.9
Hazards associated with reactive systems	35	59.3	24	40.7

Table 8: Summary of participants' feedback on other important PS topics required in the industry.

Participants	Feedback on other important PS topics	Category
Participant #6 - Graduate	Ethics engineering	Human factor
Participant #19 - Employee	Professional ethics of safety management	
Participant #14 - Employee	Safety leadership	
Participant #7 - Employee	Usage and maintenance of personal protective equipment (PPE)	
Participant #13 - Employee	Dispersion, radiation and explosion related calculations and theory	Incident management
Participant #1 - Employee	Emergency response	
Participant #2 - Graduate	Ignition control	
Participant #57 - Graduate	HAZOP study HAZID analysis	Hazard and Risk management
Participant #24 - Employee		
Participant #2 - Graduate	Hazard zoning regulation	
Participant #10 - Employee	Layers of Protection Analysis	
Participant #2 - Graduate	Simultaneous Operation Identification and Controls (SIMOPs)	
Participant #24 - Employee	Risk management	
Participant #22 - Employee	Handling heavy metals	
Participant #21 - Employee	Material safety data sheet (MSDS)	
Participant #59 - Student	Safety requirements	
Participant #38 - Employee	Statistics	Others
Participant #15 - Employee	Digitalisation	