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# Chemical process safety education in China
## An overview and the way forward

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# Chemical process safety education in China: An overview and the way forward

Mailidan Motalifu [a], Yue Tian [b], Yi Liu [a,*], Dongfeng Zhao [a], Mingqi Bai [a], Yufeng Kan [c], Meng Qi [d], Genserik Reniers [e], Nitin Roy [f]

[a] College of Chemical Engineering, China University of Petroleum (East China), Qingdao 266580, China
[b] Sinochem Safety Science Research (Shenyang) Co., Ltd, No.8-12 Shenliao Dong Road, Tiexi District, Shenyang, Liaoning, China
[c] Wanhua Chemical Group Co., Ltd, No.59 Chongqing Rd., YEDA, Yantai, Shandong, China
[d] Department of Chemical and Biomolecular Engineering, Yonsei University, 50 Yonsei-ro, Seodaemun-gu, Seoul 03722, South Korea
[e] Safety and Security Science Group, Delft University of Technology, Delft, the Netherlands
[f] Department of Public Health, California State University, Sacramento, CA 95819, USA

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ABSTRACT

The chemical process industry (CPI) in China is developing rapidly with installations becoming more complicated and integrated to meet people's rising demands for chemical-related products. However, the fast-growing CPI has caused catastrophic consequences and bad social influence due to accidents occurred in the last decades, which has threatened its sustainable development. As one of the solutions, the Chinese government is promoting chemical process safety education to train interdisciplinary graduates who understand both chemical process and loss prevention, who are skilled in technology, and how to manage risk. In this paper, we reviewed the development of chemical process safety education in China by researching syllabuses of accredited undergraduate *Chemical Engineering* and *Safety Engineering* majors in higher education institutions, discussed the associated shortcomings by analyzing the current discipline construction of the newly established major *Chemical Safety Engineering*, including education methodologies, resources, faculties, curriculum provision, and professional accreditation. Based on the analysis results, suggestions were provided to encourage institutions to strengthen chemical process safety education, thereby inherently reducing human errors and consequently improving the safety of the entire CPI.

## 1. Introduction

The chemical process industry (CPI) is the mainstay industry in China's economic structure (B. Zhang et al., 2018) and is developing rapidly as the economy grows. China's refining capacity has reached 831 million tonnes in 2018, accounting for 16.8% of the world's processing ability, becoming the second-largest petrochemical country after the USA (Qianqian et al., 2020). In China, the average scale of refineries is 4.12 million tonnes per year, with 28 plants' refining capacity exceeding 10 million tonnes, accounting for 44.5 % of the total domestic output (Chaoquan and Xuefeng, 2019). As a result, the installations are becoming large-scale, more complicated, and under operation continuously, which can have severe consequences for people, company assets, and the surrounding environment in case of accidents, resulting in huge casualties and property losses (Mkpat et al., 2018). There have been 280 large and above hazardous chemical accidents with a total of 1821 deaths over the period from 1981 to 2020 (Wei et al., 2021). Fig. 1 shows the Gross Domestic Product (GDP) and the death toll of the CPI from 2009 to 2020 in China. The death toll caused by accidents in CPI has reduced as its GDP grows. However, compared to the increasing rate of

*Abbreviations:* ABET, Accreditation Board for Engineering and Technology; AI, Artificial Intelligence; AIChE-CCPS-CS, American Institute of Chemical Engineers-Center for Chemical Process Safety-China Section; IIOT, Industrial Internet of Things; CCSA, China Chemical Safety Association; CEEAA, China Engineering Education Accreditation Association; CNPC, China National Petroleum Corporation; CPI, Chemical Process Industry; CPS, Cyber-physical Systems; CSB, US Chemical Safety and Hazard Investigation Board; CSC, China Scholarship Council; GDP, Gross Domestic Product; HAZOP, Hazard and Operability Study; IChemE, Institute of Chemical Engineers; SAChE, Safety and Chemical Engineering Education; SMEs, Small and Medium-sized Enterprises; SI, Safety Intelligence; UAB, University of Alabama at Birmingham; UPC, China University of Petroleum (East China); VR, Virtual Reality.

* Corresponding author.at: College of Chemical Engineering, China University of Petroleum (Qingdao), Qingdao 266580, China.
*E-mail address:* liuyi@upc.edu.cn (Y. Liu).

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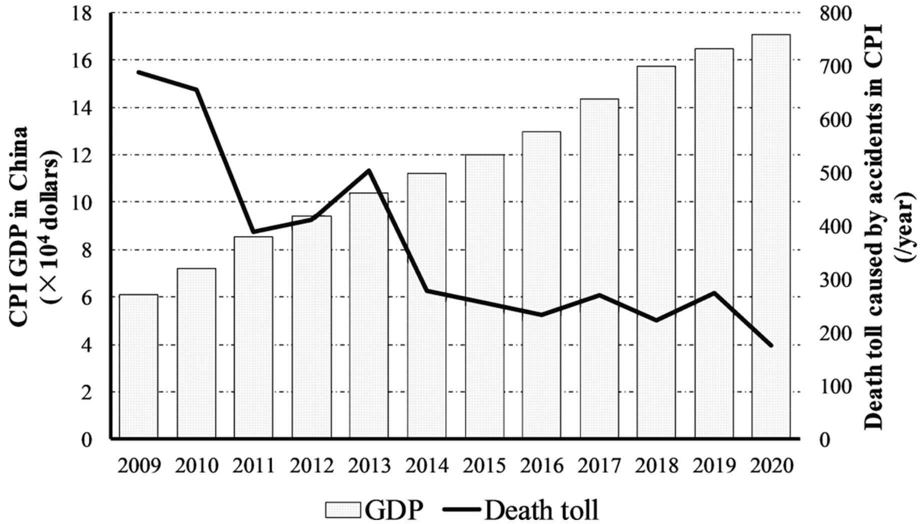


**Fig. 1.** GDP and death toll of CPI from 2009 to 2020 in China.

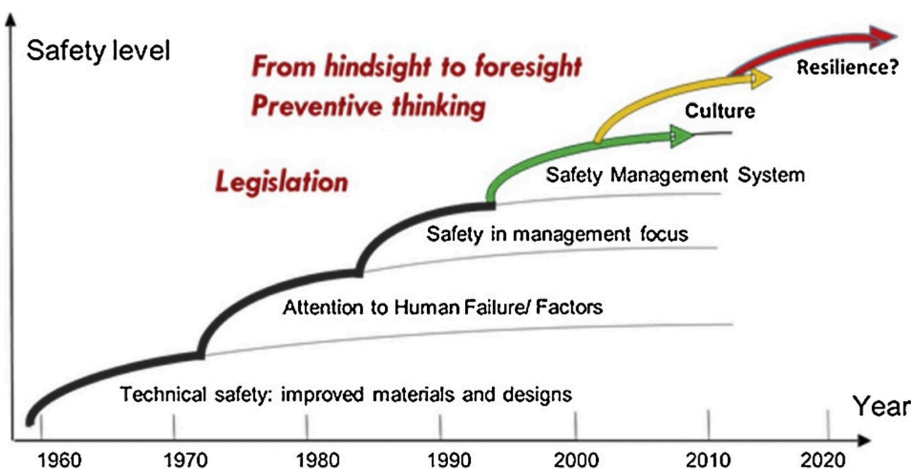


**Fig. 2.** Development of Loss Prevention (Pasman and Fabiano, 2021).

the GDP, the decreasing rate of the death toll is relatively slow, which even rebounded in several years. This indicates that serious accidents in CPI have not been effectively controlled, and their scale, losses, and public impact are becoming more and more significant.

Alarmed by catastrophic accidents in CPI, various approaches, tools, and procedures have been developed by researchers and industries. According to (Pasman and Fabiano, 2021), attention was paid to different aspects of loss prevention over the years, as shown in Fig. 2. The emphasis in earlier decades was to improve technical safety through engineering, while attention shifted to organizational and human factors today. In this context, chemical process safety education was proposed and evolved, with organizations such as the Safety and Chemical Engineering Education (SAChE) established in 1992 (Spicer et al., 2013), aiming to improve the competence and safety awareness of graduates using various teaching methods, curriculum, and education resources, consequently enhancing the sustainable development of CPI.

Since personnel participation is an important part of each aspect in Fig. 2, especially the latter aspects in which human and organization factors are emphasized, the training for personnel to make the right decisions and responses is the key to accident and loss prevention. A developed chemical process safety education in one nation can supply employees possess the abilities of chemical process safety design, equipment management, operation control, safety production technology, and management, etc., which can guarantee reducing incident rate through engineering, safety management, human factors, and safety culture. China's chemical process safety education is still in its immature stage (Chen et al., 2021). According to the statistics of the Ministry of Emergency Management of China, there are less than 3,000 graduates with a chemical process safety education background every year, while the demand for such talents is about 30,000 per year in China, resulting in a critical shortage of graduates in chemical process safety (Qi and Zhu, 2019). Therefore, China's chemical process safety education is not only urgent to be developed in quantity but also needs to be improved in quality to meet the increased standard for safety production of CPI.

A great number of studies have been carried out on chemical process safety education by researchers from a variety of perspectives. Reviews were conducted from different perspectives. (Mkpat et al., 2018) presented a systematic review towards process safety education in universities, professional training, and government regulatory agencies. (Willey et al., 2020) reviewed methods for teaching hazard analysis to undergraduate and postgraduate students in *Chemical Engineering*, including examples of the checklist, HAZOP, and bowtie analysis. (Boogaerts and Toeter, 2021) defined, selected, and reviewed concepts of process safety education based on analysis of chemical process incidents and literature review. (Khan et al., 2021) reviewed process safety concerns caused by chemical system digitalization and suggested corresponding updates in the Chemical Engineering undergraduate curriculum. Some courses or programs were introduced in detail. (Dee

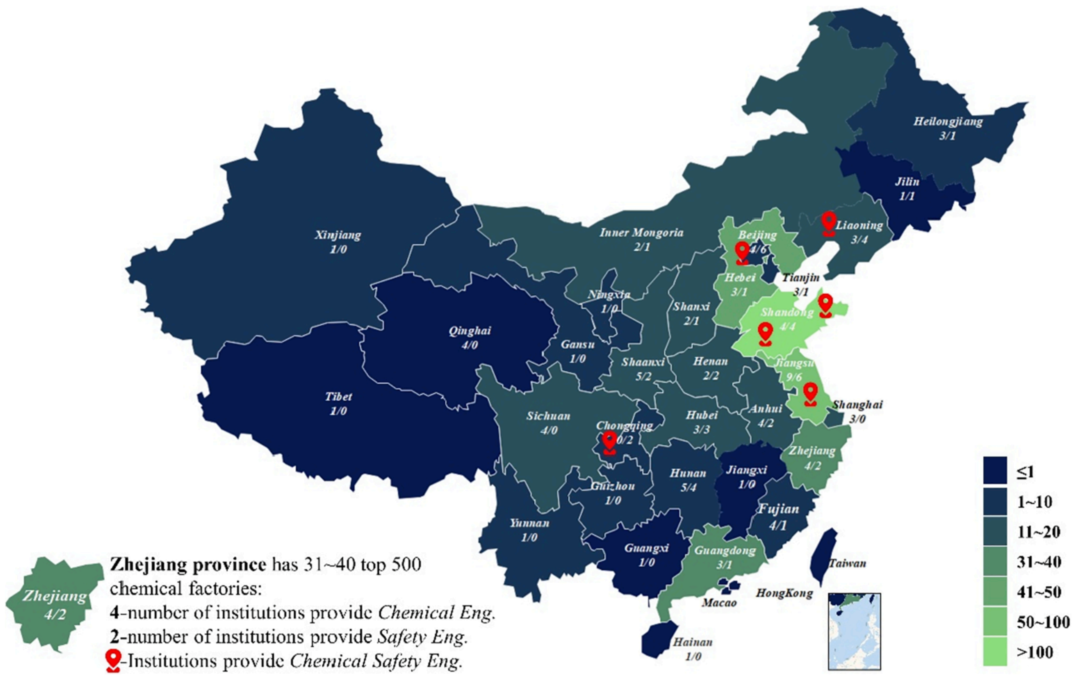


**Fig. 3.** Geographical and quantity distribution of CEEAA accredited institutions in mainland China.

et al., 2015) stated the main difficulties of incorporating process safety into *Chemical Engineering* at the undergraduate and postgraduate levels in USA universities. (Boogaerts et al., 2017) focused on industry-academic collaborated Advanced Master Class while (Perrin et al., 2018) reviewed and updated the French curriculum “Process safety” for *Chemical Engineering* undergraduate and postgraduate students. (Perrin and Laurent, 2020) provided a process safety teaching aid for *Chemical Engineering* education of postgraduate students. (Swuste et al., 2021) described and assessed the current development of postgraduate safety courses in Europe. Specifically paying attention to process safety education in China, (J. Zhang et al., 2018) analyzed education conditions about general safety discipline in China’s higher education institutions. (Yang et al., 2020) provided a complete bibliometric analysis of process safety research in China. (Chen et al., 2021) developed a novel chemical process safety education model for Chinese universities. (Laciok et al., 2021) conducted an overview of *Safety Engineering* education in China. Although these papers provided valuable insights on safety education in general while focusing on China, there is a lack of comprehensive analysis on the status of chemical process safety education. Given the highly complex and fast-growing nature of CPI as mentioned above, a study specifically focusing on chemical process safety education in China is necessary.

This paper presents a detailed analysis of chemical process safety education in Chinese higher education institutions to promote its further improvement. In Section 2, the development of chemical process safety education in China was reviewed. In Section 3, the current discipline construction of the *Chemical Safety Engineering* major was analyzed from various aspects, while focusing on the China University of Petroleum (East China) (UPC) as representative. We proposed important suggestions in Section 4 for further improvement of chemical process safety education. Conclusions are drawn in Section 5, including the limitations of this study.

## 2. Chemical process safety education in China

### 2.1. Safety Engineering and Chemical Engineering majors

In China, the chemical process safety education is originated from two majors: *Safety Engineering* and *Chemical Engineering,* and is developed via a merge and extension of relevant courses in these two majors’ syllabuses.

*Safety Engineering* was established as a second-level major in 1998 and falls under the first-level discipline Safety Science and Engineering, which was established in 1992 (Ruipeng, 2018). Until 2021, there are 185 universities and colleges in China that provide *Safety Engineering* undergraduate major (Ministry of Education of PRC, 2021), whose contents consist of the causes, development, and consequences of accidents in different industries and human activities in attempting to prevent, control and respond to disasters. *Chemical Engineering*, founded in 1927, has a longer history and is more developed in China. Until 2021, 390 higher education institutions offer Chemical Engineering undergraduate majors (Fengbao, 2019), dedicated to training graduates capable of analyzing and researching chemical processes and proficient in simulation and design.

China became the official member of the “Washington Accord” in 2016 (Ji et al., 2018), which indicates that all diplomas accredited by the China Engineering Education Accreditation Association (CEEAA) are acknowledgeable by member countries of the “Washington Accord”. Until Jan. 2021 (CEEAA, 2021), CEEAA certification covered only 20% of both *Chemical Engineering* and *Safety Engineering* majors with 79 and 45 institutions respectively, as exhibited in Table A1. The geographical and quantity distribution of these accredited institutions and the top 500 chemical factories in mainland China are presented in Fig. 3. The Jiangsu province (15), Beijing (10), Hunan province (9), and Shandong province (8), are four provinces located the most CEEAA accredited *Chemical Engineering* and *Safety Engineering* majors. The newly-promoted *Chemical Safety Engineering* major is mainly growing on the east coast of China. At the same time, more than one-third of the top 500 chemical factories were established in Jiangsu and Shandong provinces. In Central China, the number of accredited institutions in each province is under 10, with a total of 107 large-scale chemical factories. None of the universities or colleges’ *Safety Engineering* has been accredited in 12 provinces, including most parts of Western China, such as Tibet and Qinghai provinces. Therefore, the geographical and quantity distribution of chemical plants, which is consistent with population and economic distribution in China, determines the advancement of chemical engineering and safety engineering majors.

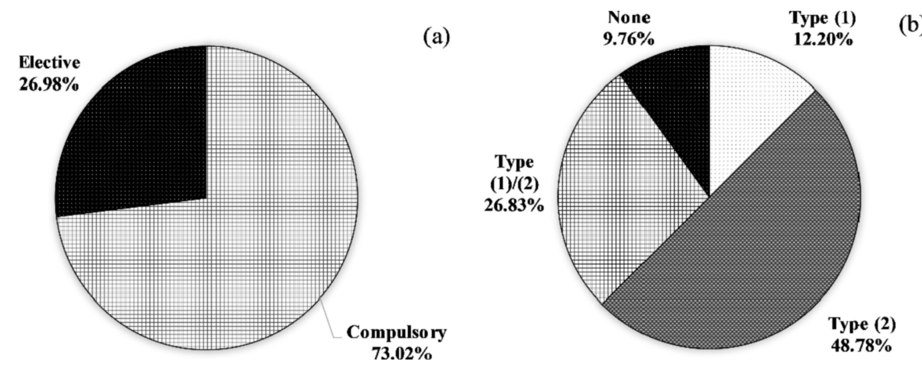


**Fig. 4.** Chemical process safety curriculum in *Chemical Engineering* (a) and *Safety Engineering* (b) majors in China.

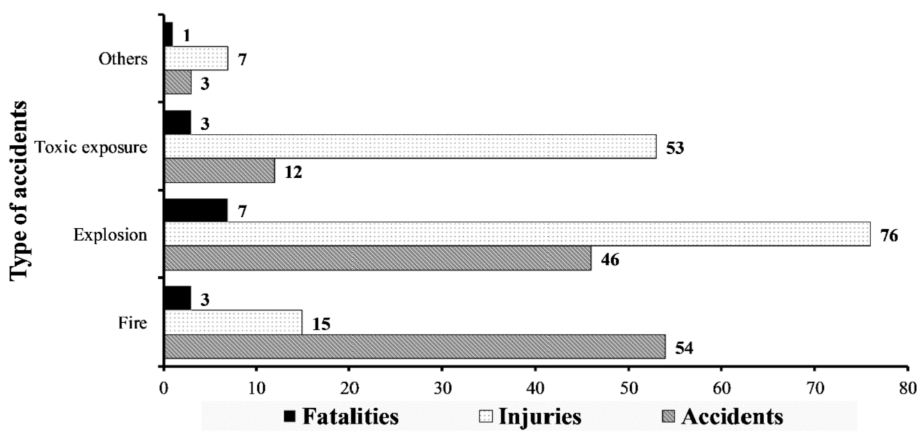


**Fig. 5.** Distribution of types and casualties of chemical laboratory accidents.

### 2.2. Chemical process safety courses in safety Engineering and Chemical Engineering

104 CEEAA accredited *Safety Engineering* (63) and *Chemical Engineering* (41) majors were researched by exploring through the relevant official websites and surveys via email. We found that loss prevention curricula are often added into the Chemical Engineering syllabus while chemical engineering knowledge is being taught to safety talents. The detail of the chemical process safety curriculum in two majors are presented in Fig. 4. Moreover, fundamental chemistry and physics are included in the required courses of both majors.

Dedicated chemical process safety courses have 100 frequency in all CEEAA accredited *Chemical Engineering* majors (Yao et al., 2021), because process safety contents are required in *Chemical Engineering* majors by CEEAA standards. As shown in Fig. 4a, 73% of institutions added chemical process safety compulsory courses in the syllabus while 27% of them offered elective ones. The most popular curriculum is *Chemical Safety and Environmental Protection*, followed by *Chemical Process Safety*, *HSE, Chemical Safety Assessment*, etc. Furthermore, nearly 84% of all institutions established only one chemical process safety course, and the credit differ from 0.5 to 3 over various universities and colleges. It is clear the majority of institutions with *Chemical Engineering* major are starting to pay attention to chemical process safety education. However, a single dedicated course is far from sufficient (Pintar, 1999). In *Chemical Engineering* majors, academic experiments are often required. We analyzed chemical laboratory accidents that occurred in higher education institutions in China from 2001 to 2021 based on the accident database of the Chemical Accident Information Network (NRCC, 2021; Zonghong et al., 2021). There was a total of 115 accidents, resulting in 14 fatalities and 151 injuries, as shown in Fig. 5. 33% of all accidents were caused by students' violation of operating procedures (24), operation error (16), and lack of protection measures (10), indicating safety awareness of *Chemical Engineering* students is in the need of improvement. Most chemical engineers in CPI are graduated from the *Chemical Engineering* major, the lack of safety education can lead to little understanding of the hazard identification and loss prevention in operation and designing of chemical processes.

In *Safety Engineering* majors, two types of courses are taken into consideration: (1) courses focusing on professional knowledge of chemical engineering such as *Chemical Principle*, *Mechanical Foundation of Chemical Equipment*, and *Chemical Instrumentation.* (2) dedicated courses of chemical process safety education, and the most common curriculum is *Chemical Process Safety,* which was listed in 70% of *Safety Engineering* syllabuses. As shown in Fig. 4b, about 10% of investigated institutions did not include chemical process safety education, while 12% and 49% established lessons only in type (1) and type (2) respectively. About 27% of institutions set up additional type (1) courses while covering type (2) curriculum. It is clear that most universities and colleges choose to cover chemical process safety education in one or two dedicated courses. This is because the safety discipline is an interdisciplinary and comprehensive science (J. Zhang et al., 2018), involving a wide range of subjects, different universities often concentrate on various research directions, such as transportation, petroleum, and mining industries, so few of them focus on the chemical process safety. The curriculum settings of *Safety Engineering* majors in different colleges and universities in China are discussed in (Ma et al., 2021), to which the reader is addressed for further details. Many of the safety management personnel in CPI in China graduated from *Safety Engineering* majors. Although dedicated chemical process safety courses are being included, graduates from *Safety Engineering* do not have adequate chemical engineering knowledge such as chemical reaction engineering and chemical process control. Safety personnel may not understand the inherent

**Table 1**
Official documents promoting chemical process safety education in China.

| Year | Main official documents and their main contents |
|---|---|
| 2012 | *Notice on Holding a Symposium on the Training of Chemical Safety Engineers in Colleges and Universities*<br>The document was released jointly by the General Office of the State Administration of Work Safety and General Office of the Ministry of Education in 2012, aiming to guide and promote the training of chemical safety engineers in universities and colleges, improving the safety management capability and safety technology level of the CPI. |
| 2014 | *Guidance on Reinforcing the Education of Chemical Process Safety Personnel*<br>The document was released jointly by the Ministry of Education and the State Administration of Work Safety in 2014, aiming to promote sustainable development and process safety within the CPI and cultivate high-quality engineers on chemical process safety. |
| 2016 | *Notice of the General Office of the State Council on the Issuance of a Comprehensive Safety Control Plan for Hazardous Chemicals*<br>The document was released by the General Office of the State Council in 2016, putting forward the requirements of "promoting the region to accelerate the cultivation of the chemical engineers, carrying out the on-line education of chemical safety, and enhancing the management of chemical safety" again. |
| 2017 | *The Seminar for Chemical Safety Engineers*<br>The seminar aimed to respond to the call of the Ministry of Education and the State Administration of Work Safety and pointed out the huge demand for chemical safety engineers from the CPI. The demand for chemical safety engineers is about 30,000 per year in China, but less than 3,000 qualified undergraduates from universities or colleges graduated each year, and it is significant and imminent to strengthen the cultivation of chemical process safety engineers. |
| 2017 | *The Report about the Comprehensive Implementation Plan for the Administration of Hazardous Chemicals in the Education System*<br>The document is a report from the General Office of the Ministry of Education to the State Council, which puts forward the requirements on the cultivation of chemical safety engineers: adjusting and optimizing program settings and encouraging the relevant universities or colleges to explore and establish an undergraduate program of *Chemical Safety Engineering.* |
| 2018 | *The First Undergraduate* program *of Chemical Safety Engineering*<br>The Ministry of Education has approved the first undergraduate program of *Chemical Safety Engineering* at the China University of Petroleum (Eastern China). |
| 2019 | *The Second Undergraduate* program *of Chemical Safety Engineering*<br>The Ministry of Education has approved the second undergraduate program of *Chemical Safety Engineering* in the Liaoning petroleum University of Education. |

complexity and hazard of chemical processes, and have little understanding of the development characteristics and consequences of chemical accidents, causing poor safety culture and inadequate safety management in CPI.

### 2.3. The establishment of the Chemical safety Engineering major

In recent years, the frequently occurring severe accidents in CPI have attracted significant attention from the Ministry of Education and the Ministry of Emergency Management of China. Table 1 shows the official documents issued by the government to promote the development of chemical process safety education in China since 2012. With the government's support, the first *Chemical Safety Engineering* major was established in 2018, which integrates the fundamental theories of *Chemical Engineering* and *Safety Engineering* majors. Its establishment is the starting point of the Chinese government promoting chemical process safety education to the next level and has a significant contribution to reducing risk in CPI through education. Until Jan. 2021 (CEEAA, 2021), there have been 6 universities that started the *Chemical Safety Engineering* major in China, as presented in Fig. 3. The detail of the Chemical Safety Engineering major at UPC was introduced in Section 3.

## 3. *Chemical safety Engineering* major in China

Chemical process safety education in China has made significant progress by reforming the education system and learning from foreign universities' success. UPC is well-known for its petrochemical-related education in China and is one of the universities first establishing an undergraduate program targeting chemical process safety education. Based on years of chemical process safety education experience, UPC has formed a compound training mode including education method, curriculum provision, and other critical educating aspects. The current status of the *Chemical Safety Engineering* major in China was analyzed below while focusing on UPC as an example. The education mechanism and curriculum at UPC were given in our previous works (Liu et al., 2020, 2018; Meng et al., 2018).

### 3.1. Education mechanism

#### 3.1.1. Multi-platform cooperation

To better integrate the process safety and chemical engineering, multi-platform cooperation among government, CPI and education institutions was established, as shown in Fig. 6. Under this cooperation, a "dual linkage mechanism" was formed in the theory of "Government Policy as Guidance, University Design as Core, Industry promoting as assistance, Student Participation as improvement" to improve chemical process safety education. "Dual linkage mechanism" refers to the external linkage between the universities, the government, and CPI, and the internal connection between the universities and students. External connection realizes the top-level syllabus design, while internal linkage

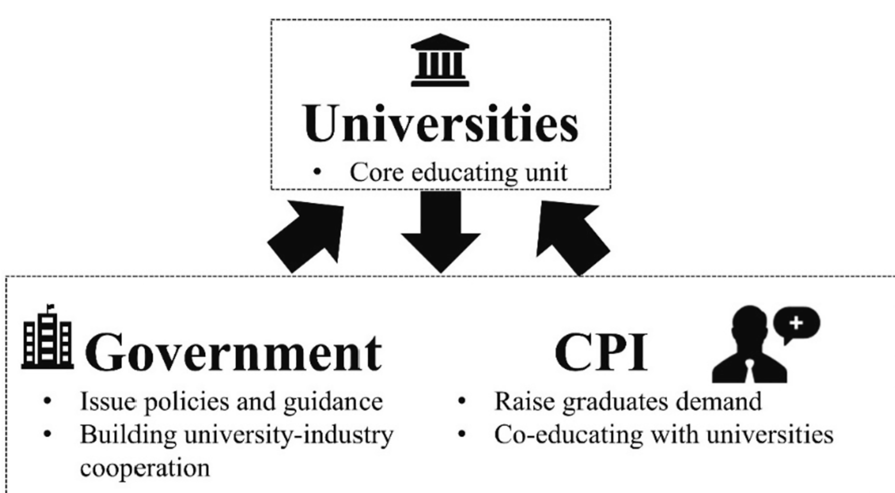


**Fig. 6.** The multi-platform cooperation among government, CPI and education institutions.

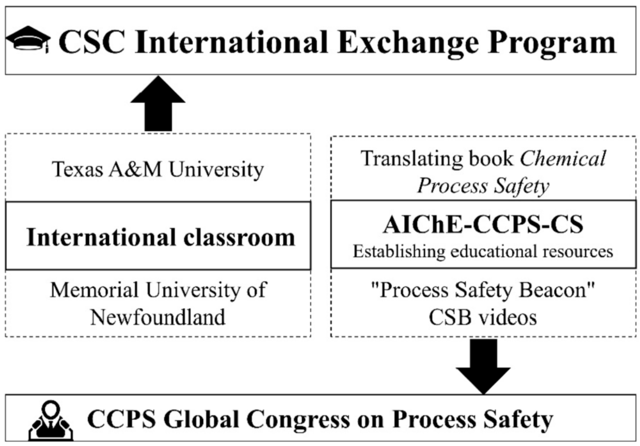


**Fig. 7.** The international cooperation platform.

realizes the improvement of education effeteness.

At UPC, the Ministry of Education of China and the State Administration of Work Safety have issued education guidance. The university and the China Chemical Safety Association (CCSA) have jointly implemented education goals, education standards, and curriculum provision. This training system was then tested in CPI. As the leading participant, students have to take all aspects of the curriculum, more importantly, they need to participate in engineering practice in CPI to improve the learning effect further.

### 3.1.2. International cooperation

Chinese universities are becoming more and more innovative in international exchanges. For example, UPC has established a global classroom, in which students share classes and earn credits through a joint partnership with students from Texas A&M University. Through English teaching methods and foreign teaching materials, students can experience American university classrooms in China. During the course, the teachers comprehensively introduce toxic gas leakage and diffusion, fire and explosion, runaway reaction, risk identification, and chemical risk assessment methods involved in chemical processes. They formulate corresponding homework and assessment methods according to the content of the class, which is beneficial to students to exercise and improve their learning and communication ability.

At the same time, UPC, Texas A&M University in the United States, and the Memorial University of Newfoundland in Canada carry out the CSC International Exchange Program for outstanding undergraduates, implementing a 3 + 1 + 1 joint program. The chemical safety international classes set up by three universities support students to participate in various scientific and technological competitions.

To keep students updated on the latest research status and progress of chemical process safety in time, the American Institute of Chemical Engineers-Center for Chemical Process Safety-China Section (AIChE-CCPS-CS), which is located at UPC, employs a large number of educational resources from CCPS to promote resource sharing, including CCPS Global Congress on Process Safety, more than 100 issues of "Process Safety Beacon", and more than 20 issues of translated US Chemical Safety and Hazard Investigation Board (CSB) videos. The cooperation with foreign universities and AIChE forms the international cooperation platform, as shown in Fig. 7.

## 3.2. Curriculum provision

As stated in Section 2, at present, chemical process safety is taught in the form of courses in *Safety Engineering* or *Chemical Engineering* majors in most universities and colleges instead of an independent discipline. In China, relevant departments and universities lack evaluation and research on the quantity and quality of these courses, resulting in an ineffective curriculum system and students' uncomprehensive knowledge structure. In the following subsections, we take UPC as an example to elaborate the curriculum for undergraduates and postgraduates.

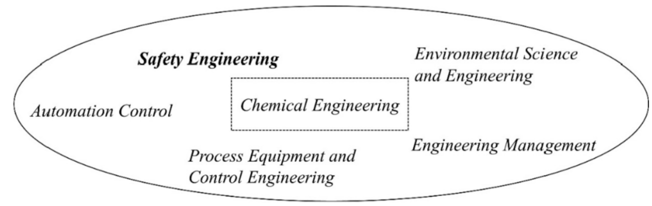


**Fig. 8.** Multidisciplinary collaboration.

### 3.2.1. Multidisciplinary collaboration

Chemical process safety education is conducted through interdisciplinary integration between multiple disciplines, including fundamental theories of *Environmental Science and Engineering*, *Engineering Management*, *Automation Control*, etc. The multidisciplinary collaboration method is mainly based on *Chemical Engineering*, assisted by *Safety Engineering* integrating other disciplines, as shown in Fig. 8. The method strengthens the inherent characteristics of chemical process safety, highlights the role of process safety in CPI to ensure the students can develop in multiple fields and adapt to the demands of CPI and society.

### 3.2.2. The undergraduate level

As the first establishing *Chemical Safety Engineering* undergraduate major in China, UPC set up a collaborative and interconnected curriculum system. In addition to some introductory courses, more than forty specialized courses in chemical process safety have been developed. These curricula involve basic knowledge and technical aspects of chemical process safety and the construction of psychological and safety concepts, including chemical process, safety theory and technology, instrument safety, equipment safety, environmental protection, and occupational health. The core curriculums are shown in Fig. 9.

### 3.2.3. The postgraduate level

The Advanced Seminar program at UPC for chemical engineers offered by the State Administration of Work Safety was taken as an example to elaborate the current training mode for the postgraduate level in China. The primary target audience of the Advanced Seminar is the operators and managers in chemical production, storage, and transportation, etc. After more than ten years of practice, this Advanced Seminar at UPC has explored various modes such as on-the-job training, combined training, and academic qualifications.

The Advanced Seminar program aims to train interdisciplinary and professional graduates fitting engineering and management positions in CPI, who understand both the chemical process and safety, who are skilled in technology and managing risk. In this regard, UPC combined theory and practice, technology and safety, compulsory and elective courses, as shown in Fig. 10. Compared with undergraduates, postgraduates have a better theoretical foundation. Therefore, more attention is paid to the training of professional and practical ability in the curriculum provision by requiring field internships in CPI. Besides, there are a series of lectures given by chemical safety experts, which focus on risk analysis, hazard identification, incident management, and process safety management.

According to (Choudhry et al., 2007), an organization with a positive safety culture is where every employee considers safety as an issue that concerns everyone. Although no special courses are offered in the curriculum provision described above, the safety culture was integrated into each curriculum during the actual teaching process. For example, by using a case study, or calculating the damage radius of certain hazard chemicals, safety awareness can be improved unconsciously as students realize the catastrophic consequences of chemical accidents. Therefore,

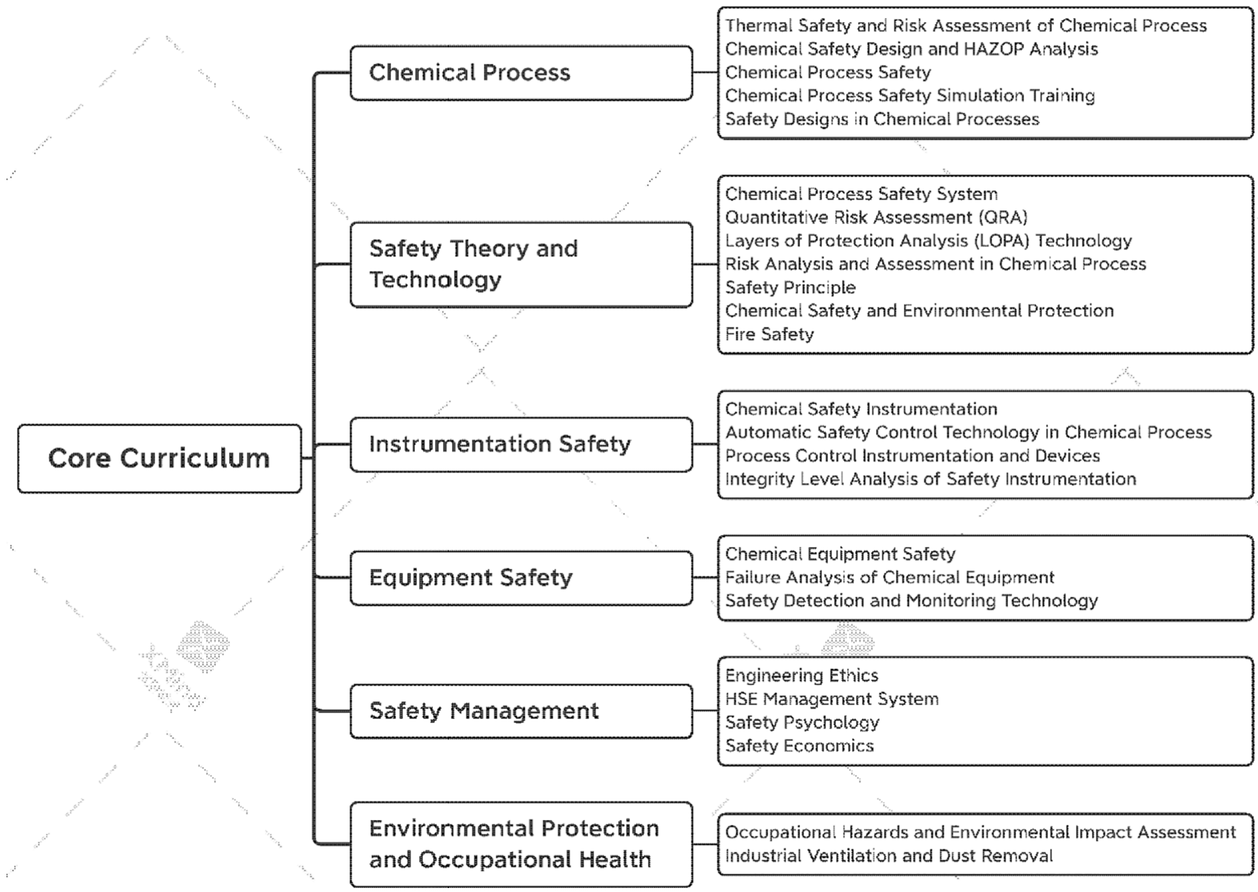


**Fig. 9.** Core courses of *Chemical Safety Engineering* major at UPC.

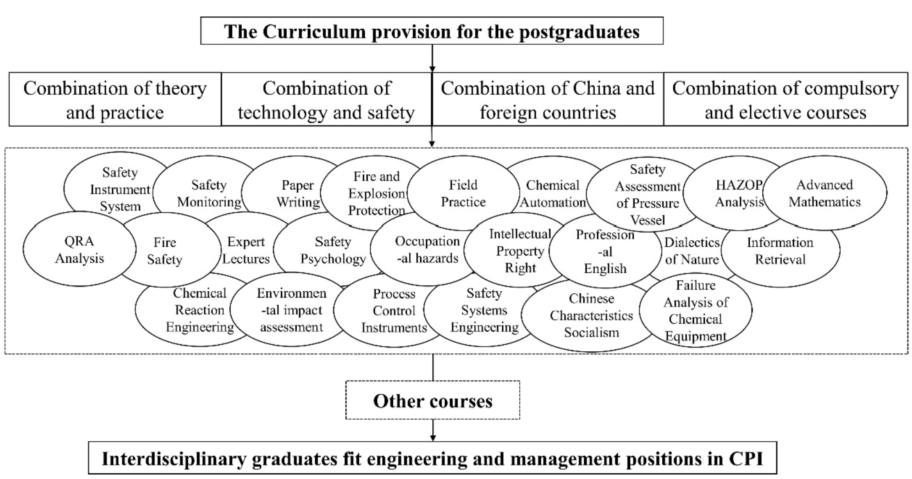


**Fig. 10.** The curriculum provision for the postgraduates.

when graduates with a chemical process safety education are working in CPI, they tend to be much more cautious than workers who are not knowledgeable in chemical process safety.

### 3.3. Teaching method

In cultivating chemical safety compound graduates, the traditional teaching method is that teachers list points and adopt the mode of "teacher speaks, students listen". In this way, students do not develop the ability to use knowledge, which leads to the disconnection between theory and reality requirements. In addition, most students tend to limit the studying content to understanding textbooks to deal with exams and grades. The lack of diversified teaching methods in China has led to the lack of "compound" of chemical engineering and process safety, making it difficult to guarantee the quality of chemical process safety compound graduates required by industries.

To promote the implementation of the curriculum provision, UPC has developed 'safety-related teaching' based on years of teaching experience, connecting the processes of teaching different professional courses using the 'safety concept' as the core element. To this end, in addition to the traditional lecture-based learning, heuristic teaching, and combination of teaching and research, teachers can guide students to complete the transformation from textbook learning to disciplinary learning, ensuring the effective implementation of the curriculum provision. In addition, the use of diversified teaching methods such as mobile classrooms and course practicum can strengthen students' safety awareness. By shifting the classroom to modern chemical plants, teachers can guide students to find and solve problems, avoiding the inconsistent combination of theoretical learning and engineering practice, significantly improving the teaching effeteness.

### 3.4. Scientific background of faculties

The development of chemical process safety education and graduates mainly depends on the quality and ability of faculties (Xue, 2018). As the chemical process safety education developed, the number of relevant faculties improved steadily. However, the structure of the current teaching staff still has many drawbacks. Firstly, the teaching staff was directly enrolled into universities or colleges after obtaining master's or doctoral degrees. Most of them possess rich theoretical knowledge but lack engineering experiences. Few industrial or academic associations in China provide regular process safety training for faculties to compensate for this shortcoming. On the other hand, few faculties who teach process safety have related chemical learning experience. They have diverse educational backgrounds, such as coal mining, construction, aviation, etc.

Furthermore, Chinese universities lack practical standards and solutions for engineers being full-time or part-time university teachers. First of all, engineers lack an understanding of the teaching profession, resulting in unqualified teaching quality. Second, these engineers are not systematically evaluated. Most of them lack comprehensive theoretical knowledge to support all teaching tasks.

### 3.5. Educational resource

#### 3.5.1. Textbook material

There are mainly two ways to obtain teaching materials related to chemical safety education in China: one is to translate classic foreign chemical safety-related and representative teaching materials, such as *Chemical Process Safety:Fundamentals with Applications* and *A Practical Approach to Hazard Identification for Operations and Maintenance Workers*, etc. The other kind is self-editing summaries or practical textbooks, based on the development needs of the chemical industry, summing up past experiences, such as *Chemical Process Safety*, *Direction on Chemical Process Safety Management*, and *Guidelines for Process Hazard Analysis of Refinery Units in Service*, etc. Whether it is translated or self-edited textbooks, the relevant information of textbooks can be found online, making it greatly convenient for teachers and students to select and purchase, realizing the sharing of resources between universities. However, in the lack of standards, the textbooks for chemical process safety education in China are not unified, leading to students' uncomprehensive knowledge structure.

#### 3.5.2. Additional resources and experiment equipment

With the supports of AIChE-CCPS-CS, the SAChE supplement materials and CSB accident investigation reports, video teaching aids (Louvar, 2013) are used by universities and colleges. In recent years, the Ministry of Emergency Management also issued videos based on disastrous accident investigation reports used by faculties for chemical process safety education.

In the meantime, UPC has built various engineering and simulation laboratories for chemical process safety education, involving fire, explosion, leakage, detection and monitoring, electrical and instrumentation, with more than 100 sets of equipment. There is a safety analysis simulation software system for teaching and scientific research, including the fire and explosion risk simulation software AutoReaGas and FLACS. Furthermore, some small and pilot chemical experimental devices in the laboratory also provide chemical process safety education facilities.

## 4. Suggestions for further improvement

### 4.1. Promoting the chemical process safety education through different majors

As previously outlined, chemical process safety education in China is mainly carried out through 3 majors including *Chemical Engineering*, *Safety Engineering*, and *Chemical Safety Engineering*. First, besides dedicated safety courses, the knowledge of loss prevention in CPI should be integrated into all *Chemical Engineering* professional curriculum, although it will be challenging for teachers (Pintar, 1999). Second, universities and colleges are advised to establish chemical process safety direction in *Safety Engineering* majors same as Nanjing Tech University. Third, more higher education institutions and higher vocational colleges should establish the *Chemical Safety Engineering* major with the governments' support to reduce the shortage of graduates in chemical process safety. Furthermore, the overall chemical process safety education development is unbalanced in eastern and western China, corresponding strategies should be taken by the Chinese government.

### 4.2. Promoting the international accreditation of the Chemical Engineering majors

For engineering disciplines, professional accreditation is not only a quality assurance system but also a vital platform for international co-recognition (Ronald J et al., 2006; Sean J et al., 2006). At present, the international accreditation of the *Chemical Engineering* undergraduate major mainly refers to the American and European accreditation standards and indicators in China. Tianjin University firstly achieved the IChemE accreditation in 2008; East China University of Science and Technology achieved the ABET accreditation in 2011, which is the first university to achieve the ABET accreditation in China, followed by Tsinghua University in 2016 (Manling et al., 2021). Overall, only three universities achieved international accreditation. Furthermore, as analyzed in Section 2, only 20% of *Chemical Engineering* majors have been accredited by CEEAA, which meets the standards of the "Washington Accord". Therefore, the accreditation rate of the *Chemical Engineering* major in Chinese universities and colleges is in urgent need to improve for the following aspects:

a) More professional training programs will be developed based on accreditation standards and complete chemical process safety education curriculum systems.
b) Students' abilities will be further developed, including designing and conducting experimental operations, analyzing and processing experimental data, designing systems, units, or processes based on requirements, solving engineering problems, and applying techniques and skills to engineering practices.

### 4.3. Strengthening practicum requirements in higher education institutions

On-site internships in chemical plants, where students combine theories learned in the classroom with working experiences, are essential parts in improving the teaching effectiveness of chemical process safety education. All students in the *Chemical Engineering* major should be required to finish the different levels of internships during the four-year undergraduate education. Practicum requirements can remedy the insufficient process safety courses in *Chemical Engineering* because safety training and exams are mandatory before entering factories. Besides, students must follow all safety legislation and be part of the safety culture of chemical companies, enhancing their safety awareness and understanding various safety management methods used by different departments to prevent accidents involving flammable, toxic, and highly reactive chemicals.

Therefore, universities and colleges should establish strong cooperation with leading chemical companies to prepare students for industry 4.0 (Zhongbing et al., 2021). On-site and off-site teaching was recommended in engineering practice (Niu and Zhang, 2021), where safety education, processes, safety system, and plant layout was introduced first in off-site courses before further training on-site.

### 4.4. Improving the engineering background of faculties

First-class chemical process safety education requires the faculty team to possess comprehensive theoretical knowledge, a robust professional practice ability, and rich practical engineering experience. Improving the engineering practice ability of faculty members should, therefore, follow these two aspects:

a) Through government supervision and guidance, employees with high skills and rich practical experience in CPI may be invited and hired as part-time advisors for chemical process safety education, allowing students to learn from the insights and experiences of employees from different departments.
b) Under the cooperation with Chinese and foreign associations, workshops should be held for the faculties who teach chemical process safety. Professional experts from well-known universities, colleges, CPI, and designing institutes should be invited.

### 4.5. Leading students to safety 4.0

As the processing industry is making the transition towards Industry 4.0 (Schwab, 2017) using 4.0 technologies, including artificial intelligence (AI), industrial internet of things (IIOT), and cyber-physical systems (CPS), process safety is also entering Safety 4.0 era. On the one hand, chemical companies are updating their installations significantly through digitization and automation (Vaccari et al., 2020), developing smart factory, intelligent manufacturing, and intelligent logistics. On the other hand, process safety is facing new challenges and opportunities in the age of intelligence and big data. For example, gathering and analyzing data using AI and machine learning (Pasman and Fabiano, 2021), HAZOP 4.0 (Mokhtarname et al., 2020), or accomplishing safety management using Safety intelligence (SI) (Wang, 2021). As a result of Industries 4.0, the upcoming generation of process engineers are expected to be proficient in IT skills as they will spend more time with digital twins than actual equipment and plants (Lee et al., 2019).

Firstly, seminars and lectures on the topic of Industry 4.0 are advised to increase students' awareness of Safety 4.0, which can be given by professors, engineers, and practitioners who own 4.0 technology (Laciok et al., 2021). Secondly, Virtual Reality (VR), big data, and AI can be used as new tools to educate young engineers. Experiments and equipment operations, or the practical matters that are difficult to understand in the classroom, can be built using VR (Nazir et al., 2012), which can significantly enhance the efficiency and attractiveness of cognitive processes with diverse visual, auditory, and even tactile experiences (Paszkiewicz et al., 2021). At last, digitalization concepts need to be integrated into professional curriculum, allowing students to transform chemical engineering knowledge into intelligent procedures (Khan et al., 2021; Teles dos Santos et al., 2018).

## 5. Conclusions

In this work, the current status of chemical process safety education in China was overviewed. First, only 20% of *Safety Engineering* and *Chemical Engineering* majors in China have been accredited by CEEAA, which is mainly located in East and Central China. Second, chemical process safety courses have 100 frequencies in all CEEAA accredited *Chemical Engineering* majors, nearly 84% of which established only one chemical process safety course. Two types of courses were considered in *Safety Engineering* majors, about 10% of which did not include chemical

**Table A1**
List of universities or colleges with the *Chemical Engineering* undergraduate programs accredited by CEEAA since 2007 in China (CEEAA, 2021).

| | Universities or Colleges | Major | Validity Period of Accreditation | |
|---|---|---|---|---|
| | | | From | To |
| 1 | China University of Mining and Technology (Beijing) | Safety Engineering | Dec. 2008 | Dec. 2025* (except Jan. 2018 to Dec. 2019) |
| 2 | China University of Geosciences(Beijing) | Safety Engineering | Jan. 2010 | Dec. 2015 |
| 3 | Northeastern university | Safety Engineering | Jan. 2010 | Dec. 2024* |
| 4 | Liaoning technical University | Safety Engineering | Jan. 2010 | Dec. 2024* |
| 5 | Capital University of Economics And Business | Safety Engineering | Jan. 2011 | Dec. 2025* |
| 6 | Anhui University of Science & Technology | Safety Engineering | Jan. 2011 | Dec. 2025* |
| 7 | Nanjing University of Science And Technology | Safety Engineering | Jan. 2012 | Dec. 2023 |
| 8 | China Jiliang University | Safety Engineering | Jan. 2012 | Dec. 2023 |
| 9 | Shandong University of Science and Technology | Safety Engineering | Jan. 2013 | Dec. 2024* |
| 10 | Henan Polytechnic University | Safety Engineering | Jan. 2013 | Dec. 2025* (except Jan. 2016 to Dec. 2016) |
| 11 | Central South University | Safety Engineering | Jan. 2013 | Dec. 2025* (except Jan. 2016 to Dec. 2019) |
| 12 | Beijing Institute Of Technology | Safety Engineering | Jan. 2014 | Dec. 2022 |
| 13 | Xi'an University Of Science And Technology | Safety Engineering | Jan. 2014 | Dec. 2025* |
| 14 | Nanjing Tech University | Safety Engineering | Jan. 2015 | Dec. 2026* |
| 15 | Changzhou University | Safety Engineering | Jan. 2015 | Dec. 2023 |
| 16 | Zhejiang University Of Technology | Safety Engineering | Jan. 2015 | Dec. 2023 |
| 17 | North China Institute Of Science And Technology | Safety Engineering | Jan. 2016 | Dec. 2024* |
| 18 | China University of Mining and Technology | Safety Engineering | Jan. 2016 | Dec. 2024* |
| 19 | University Of South China | Safety Engineering | Jan. 2016 | Dec. 2024* |
| 20 | University Of Science and Technology Beijing | Safety Engineering | Jan. 2017 | Dec. 2026* (except Jan. 2020 to Dec. 2020) |
| 21 | Inner Mongolia University Of Science and Technology | Safety Engineering | Jan. 2017 | Dec. 2019 |
| 22 | Jilin Jianzhu University | Safety Engineering | Jan. 2017 | Dec. 2026* (except Jan. 2020 to Dec. 2020) |
| 23 | Zhengzhou University | Safety Engineering | Jan. 2017 | Dec. 2025* |
| 24 | Hunan University Of Science And Technology | Safety Engineering | Jan. 2017 | Dec. 2026* (except Jan. 2020 to Dec. 2020) |
| 25 | Taiyuan University Of Technology | Safety Engineering | Jan. 2018 | Dec. 2023 |
| 26 | Anhui University Of Technology | Safety Engineering | Jan. 2018 | Dec. 2023 |
| 27 | Fuzhou University | Safety Engineering | Jan. 2018 | Dec. 2023 |

(continued on next page)

**Table A1** (*continued*)

| | Universities or Colleges | Major | Validity Period of Accreditation | |
|---|---|---|---|---|
| | | | From | To |
| 28 | China University of Petroleum (East China) | Safety Engineering | Jan. 2018 | Dec. 2023 |
| 29 | Qingdao University of science and technology | Safety Engineering | Jan. 2018 | Dec. 2023 |
| 30 | Chang'an University | Safety Engineering | Jan. 2018 | Dec. 2023 |
| 31 | Shenyang University Of Chemical Technology | Safety Engineering | Jan. 2019 | Dec. 2024* |
| 32 | Jiangsu University | Safety Engineering | Jan. 2019 | Dec. 2024* |
| 33 | China University Of Geosciences (wuhan) | Safety Engineering | Jan. 2019 | Dec. 2024* |
| 34 | Hunan Institute of Technology | Safety Engineering | Jan. 2019 | Dec. 2024* |
| 35 | China University Of Petroleum (Beijing) | Safety Engineering | Jan. 2020 | Dec. 2025* |
| 36 | Tianjin University of Technology | Safety Engineering | Jan. 2020 | Dec. 2025* |
| 37 | Shenyang Aerospace University | Safety Engineering | Jan. 2020 | Dec. 2025* |
| 38 | Heilongjiang University of Science And Technology | Safety Engineering | Jan. 2020 | Dec. 2025* |
| 39 | Qingdao University of Technology | Safety Engineering | Jan. 2020 | Dec. 2025* |
| 40 | Chongqing University | Safety Engineering | Jan. 2020 | Dec. 2025* |
| 41 | Nanjing University of Information Science and Technology | Safety Engineering | Jan. 2021 | Dec. 2026* |
| 42 | Wuhan University of Science and Technology | Safety Engineering | Jan. 2021 | Dec. 2026* |
| 43 | Wuhan University of Technology | Safety Engineering | Jan. 2021 | Dec. 2026* |
| 44 | South China University of Technology | Safety Engineering | Jan. 2021 | Dec. 2026* |
| 45 | Chongqing University of Science and Technology | Safety Engineering | Jan. 2021 | Dec. 2026* |
| 46 | Tianjin University | Chemical Engineering | Jan.2007 | Dec.2025* |
| 47 | Beijing University of Chemical Technology | Chemical Engineering | Jan. 2008 | Dec. 2025* |
| 48 | China University of Petroleum (East China) | Chemical Engineering | Jan. 2008 | Dec. 2025* |
| 49 | Dalian University of Technology | Chemical Engineering | Jan. 2009 | Dec. 2023 |
| 50 | East China University Of Science And Technology | Chemical Engineering | Jan. 2009 | Dec. 2026* |
| 51 | Jilin Institute Of Chemical Technology | Chemical Engineering | Jan. 2010 | Dec. 2021 |
| 52 | Nanjing Tech University | Chemical Engineering | Jan. 2010 | Dec. 2021 |
| 53 | Zhejiang University | Chemical Engineering | Jan. 2010 | Dec. 2021 |
| 54 | Wuhan Institute Of Technology | Chemical Engineering | Jan. 2011 | Dec. 2022 |
| 55 | South China University Of Technology | Chemical Engineering | Jan. 2011 | Dec. 2025* |
| 56 | Zhejiang University Of Technology | Chemical Engineering | Jan. 2012 | Dec. 2023 |
| 57 | Hefei University Of Technology | Chemical Engineering | Jan. 2012 | Dec. 2023 |
| 58 | Zhengzhou University | Chemical Engineering | Jan. 2012 | Dec. 2023 |
| 59 | China University of Petroleum (Beijing) | Chemical Engineering | Jan. 2013 | Dec. 2024* |
| 60 | Sichuan University | Chemical Engineering | Jan. 2013 | Dec. 2024* |
| 61 | Shenyang University Of Chemical Technology | Chemical Engineering | Jan. 2014 | Dec. 2023 |
| 62 | Changzhou University | Chemical Engineering | Jan. 2014 | Dec. 2023 |
| 63 | Qingdao University Of Science & Technology | Chemical Engineering | Jan. 2014 | Dec. 2023 |
| 64 | Sichuan University of Science & Engineering | Chemical Engineering | Jan. 2015 | Dec. 2023 |
| 65 | Beijing Institute of Technology | Chemical Engineering | Jan. 2015 | Dec. 2023 |
| 66 | Beijing Institute Of Petrochemical Technology | Chemical Engineering | Jan. 2015 | Dec. 2023 |
| 67 | Liaoning Petrochemical University | Chemical Engineering | Jan. 2015 | Dec. 2023 |
| 68 | China University of Mining and Technology | Chemical Engineering | Jan. 2015 | Dec. 2023 |
| 69 | Anhui University | Chemical Engineering | Jan. 2015 | Dec. 2023 |
| 70 | Hunan University | Chemical Engineering | Jan. 2015 | Dec. 2023 |
| 71 | Xi'an University Of Science And Technology | Chemical Engineering | Jan. 2015 | Dec. 2023 |
| 72 | Hebei University of Science and Technology | Chemical Engineering | Jan. 2016 | Dec. 2024* |
| 73 | Nanjing University Of Science And Technology | Chemical Engineering | Jan. 2016 | Dec. 2024* |
| 74 | Zhejiang University Of Science And Technology | Chemical Engineering | Jan. 2016 | Dec. 2024* |
| 75 | Fuzhou University | Chemical Engineering | Jan. 2016 | Dec. 2024* |
| 76 | Southwest Petroleum University | Chemical Engineering | Jan. 2016 | Dec. 2024* |
| 77 | Kunming University Of Science And Technology | Chemical Engineering | Jan. 2016 | Dec. 2024* |
| 78 | Yanshan University | Chemical Engineering | Jan. 2017 | Dec. 2025* |
| 79 | Jiangsu University | Chemical Engineering | Jan. 2017 | Dec. 2025* |
| 80 | Ningbo University Of Technology | Chemical Engineering | Jan. 2017 | Dec. 2025* |
| 81 | Ocean University Of China | Chemical Engineering | Jan. 2017 | Dec. 2019 |
| 82 | Xiangtan University | Chemical Engineering | Jan. 2017 | Dec. 2025* |
| 83 | Central South University | Chemical Engineering | Jan. 2017 | Dec. 2025* |
| 84 | University Of South China | Chemical Engineering | Jan. 2017 | Dec. 2025* |
| 85 | Guangdong University Of Petrochemical Technology | Chemical Engineering | Jan. 2017 | Dec. 2025* |
| 86 | Shaanxi University Of Science and Technology | Chemical Engineering | Jan. 2017 | Dec. 2025* |
| 87 | Lanzhou University Of Technology | Chemical Engineering | Jan. 2017 | Dec. 2025* |
| 88 | Shihezi University | Chemical Engineering | Jan. 2017 | Dec. 2025* |
| 89 | Hebei University of Technology | Chemical Engineering | Jan. 2018 | Dec. 2023 |
| 90 | Taiyuan University of Technology | Chemical Engineering | Jan. 2018 | Dec. 2023 |
| 91 | Shanghai Institute of Technology | Chemical Engineering | Jan. 2018 | Dec. 2023 |
| 92 | Jiangnan University | Chemical Engineering | Jan. 2018 | Dec. 2023 |
| 93 | Huaiyin Institute Of Technology | Chemical Engineering | Jan. 2018 | Dec. 2023 |
| 94 | Anhui University Of Technology | Chemical Engineering | Jan. 2018 | Dec. 2023 |
| 95 | Hefei University | Chemical Engineering | Jan. 2018 | Dec. 2023 |
| 96 | Huaqiao University | Chemical Engineering | Jan. 2018 | Dec. 2023 |

(*continued on next page*)

**Table A1** (*continued*)

| | Universities or Colleges | Major | Validity Period of Accreditation | |
|---|---|---|---|---|
| | | | From | To |
| 97 | Fujian Agriculture And Forestry University | Chemical Engineering | Jan. 2018 | Dec. 2023 |
| 98 | Chengdu University of Technology | Chemical Engineering | Jan. 2018 | Dec. 2023 |
| 99 | Guizhou University | Chemical Engineering | Jan. 2018 | Dec. 2023 |
| 100 | Jiangsu Ocean University | Chemical Engineering | Jan. 2019 | Dec. 2024* |
| 101 | Tianjin University of Science & technology | Chemical Engineering | Jan. 2019 | Dec. 2024* |
| 102 | Tianjin University of Technology | Chemical Engineering | Jan. 2019 | Dec. 2024* |
| 103 | Inner Mongolia University Of Science and Technology | Chemical Engineering | Jan. 2019 | Dec. 2024* |
| 104 | Shanghai University Of Engineering Science | Chemical Engineering | Jan. 2019 | Dec. 2024* |
| 105 | Yancheng Institute Of Technology | Chemical Engineering | Jan. 2019 | Dec. 2024* |
| 106 | Xiamen University | Chemical Engineering | Jan. 2019 | Dec. 2024* |
| 107 | Nanchang University | Chemical Engineering | Jan. 2019 | Dec. 2024* |
| 108 | Henan University of Technology | Chemical Engineering | Jan. 2019 | Dec. 2024* |
| 109 | Guangdong University Of Technology | Chemical Engineering | Jan. 2019 | Dec. 2024* |
| 110 | Guilin University Of Technology | Chemical Engineering | Jan. 2019 | Dec. 2024* |
| 111 | Xi'an Jiaotong University | Chemical Engineering | Jan. 2020 | Dec. 2025* |
| 112 | Xi'an Shiyou University | Chemical Engineering | Jan. 2020 | Dec. 2025* |
| 113 | Qiqihar University | Chemical Engineering | Jan. 2021 | Dec. 2026* |
| 114 | Jianghan University | Chemical Engineering | Jan. 2021 | Dec. 2026* |
| 115 | Ningxia University | Chemical Engineering | Jan. 2021 | Dec. 2026* |
| 116 | North University of China | Chemical Engineering | Jan. 2021 | Dec. 2026* |
| 117 | Inner Mongolia University Of Technology | Chemical Engineering | Jan. 2021 | Dec. 2026* |
| 118 | Northeast Petroleum University | Chemical Engineering | Jan. 2021 | Dec. 2026* |
| 119 | Northeast Forestry University | Chemical Engineering | Jan. 2021 | Dec. 2026* |
| 120 | University Of Jinan | Chemical Engineering | Jan. 2021 | Dec. 2026* |
| 121 | Hubei University Of Technology | Chemical Engineering | Jan. 2021 | Dec. 2026* |
| 122 | Hunan Institute Of Engineering | Chemical Engineering | Jan. 2021 | Dec. 2026* |
| 123 | Hainan University | Chemical Engineering | Jan. 2021 | Dec. 2026* |
| 124 | Northwest University | Chemical Engineering | Jan. 2021 | Dec. 2026* |

Note: 1. The start date of the validity period is the start date of the institution's first get accredited. The end date of the validity period is the expiration date of the latest round of certification.
2. * means that the discipline meets the requirements of the CEEAA standards, but some existing problems need to be improved. The improvement report needs to be resubmitted in the third year, and the 'continuation of validity period' or 'suspension of validity period' is decided by improving the problems.

process safety education, while more than 60% of institutions offered one or two dedicated courses. Third, analysis of previous chemical laboratory accidents, and various safety research directions in different universities revealed the insufficiency of chemical process safety education in China.

The current discipline construction of the newly established Chemical Safety Engineering major was introduced. UPC established a comprehensive educational mechanism through cooperation with the government, CPI, and foreign universities. Interdisciplinary curriculum provision was offered to undergraduates and postgraduates, while safety awareness and safety culture are integrated into each curriculum so that human errors can be inherently reduced to ensure a positive safety culture within CPI. Suggestions and their implementation were proposed, including promoting the chemical process safety education in China through different majors and international accreditation. Universities and colleges are advised to strengthen the practicum requirements towards students and engineering background towards teachers while taking steps to prepare graduates for industries 4.0.

In this work, the education method, resources, and curriculum provision of UPC can provide guidance for education institutions in China. It should be noted that the investigated higher education institutions in Section 2 were limited to CEEAA accredited institutions to ensure the unity of education level. Chemical process safety education in CEEAA accredited institutions was assumed to be better than unaccredited ones. Second, only 104 of 124 accredited universities and colleges were researched because of the unavailability of related syllabuses.

## CRediT authorship contribution statement

**Mailidan Motalifu:** Resources, Writing – review & editing, Writing – original draft, Conceptualization, Data curation, Investigation. **Yue Tian:** Writing – original draft, Methodology, Investigation, Conceptualization. **Yi Liu:** . **Dongfeng Zhao:** Validation, Supervision, Resources. **Mingqi Bai:** Data curation, Project administration. **Yufeng Kan:** Writing – original draft, Methodology, Investigation. **Meng Qi:** Visualization, Writing – review & editing. **Genserik Reniers:** Supervision, Visualization, Formal analysis. **Nitin Roy:** Conceptualization, Project administration, Validation.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Appendix

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