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Developing a talent training model related to chemical process safety based on interdisciplinary education in China

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ABSTRACT

While chemical industrial development in China is growing rapidly, the corresponding safety training resources remain inadequate, which may often lead to increased risk of chemical accidents. These accidents are often associated with the negligence of safety management, poor safety hazard awareness, and lack of safety practice. In order to alleviate these prominent risk factors in chemical industries in China, our study develops a talent training model related to chemical process safety. First, we propose an approach for establishing the "talent training model" related to chemical process safety, consisting of three steps: analyzing the current status and existing problems of talent training related to chemical process safety, determining the theoretical basis and training objectives for developing interdisciplinary talents, and designing a new talent training model. Second, we establish a talent training model using the proposed method, which includes a comprehensive curriculum system, a diversified teaching pattern, and a quintuple evaluation method. Furtherly, we determine the expected outcomes of the talent training model. The research results provide an innovative chemical process safety training method that is applicable nationwide, also it works as a reference for other rapidly developing countries in the chemical process industry to improve safety within the chemical industry.

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1. Introduction

As an indispensable part of modern society, the chemical industry has brought great convenience in daily lives and significant benefits in the global economy. However, the risk and incidence of chemical accidents are also increasing (Wood and Fabbri, 2019). Over the past decades, the global chemical industry has been looking for methods to balance productivity and safety at work (Behie et al., 2020; Gao et al., 2020). Lately, with the increasing emphasis on safety production and raising awareness of safety issues, resolving this dilemma in the chemical industry has become a core issue related to the development of chemical and petrochemical enterprises (Besserman and Mentzer, 2017; Lee et al., 2016).

Chemical manufacturing involves inducing chemical reactions under high temperature, high pressure, and other hazardous conditions. During the complicated process, chemical production is often faced with a high risk of equipment and materials, strict process parameters, and it is prone to fire, explosion, poisoning, and other accidents (Wang et al., 2020). Due to these properties, once the leakage of hazardous chemical substances occurs, it is easy to cause a major accident. In addition, when the primary accident propagates to nearby devices, the consequences of the accident could expand, and possibly result in a so-called domino effect accident (Chen and Reniers, 2020). In many cases, the consequence of a chemical disaster is severe (Lecue and Darbra, 2019; Wang et al., 2020). For instance, the explosion in Tianjiayi Chemical Plant, China in 2019 resulted in 78 fatalities and more than 617 injuries, with a direct economic loss of US$ 100 million; and more recently in 2020, the explosion in Beirut, Lebanon, led to at least 177 deaths and more than 6000 injuries.

Lack of safety awareness in the workplace, insufficient safety knowledge, and inadequate safety management are essential reasons for chemical accidents (Hemmatian et al., 2014). Looking back at the long and painful history of chemical accidents, as chemical safety researchers, we have felt the urgency to find a solution

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for the difficult relationship between the rapid development of the chemical industry and inadequate safety training. To prevent major disasters in the chemical industry, some chemical experts and scholars have pointed out that the government and universities should pay more attention to chemical process safety education (Brown et al., 2019; Lenihan et al., 2020; Mkpat et al., 2018; Perrin et al., 2018; Yong and Ashman, 2019). However, the existing research on talent training related to chemical process safety mainly focuses on a specific aspect, such as curriculum development (Dee et al., 2015; Louvar, 2009; Louvar and Hendershot, 2003; Mkpat et al., 2018; Perrin et al., 2018; Perrin and Laurent, 2008; Pitt, 2012), teaching methods (García-Fayos et al., 2020; Mkpat et al., 2018), or assessment methods (Pitt, 2012). Hence, there is a lack of research on overall talent training models related to chemical process safety which take the curriculum system, teaching methods as well as evaluation methods into account. Moreover, taking the curriculum development as an example, in most universities there exists a strong preference for the integration of process safety into the existing chemical engineering curriculum (Dee et al., 2015; Louvar, 2009; Perrin and Laurent, 2008; Spicer et al., 2013), but Mkpat et al. (2018) and Perrin et al. (2018) have confirmed that the integration would limit the viability of process safety education at an undergraduate level and lead to the lack of focus on process safety. Therefore, developing a systematic talent training model related to chemical process safety, with the purpose to reduce the risk factors of the chemical industry, is an important research topic.

This research aims to propose a novel talent training model related to chemical process safety, to accelerate the talent training for chemical process safety, and to provide a guarantee for improving the safety level in the chemical industry. China's chemical industry has become the largest around the world and played a dominant role in the growth of the world chemical market (Chen and Reniers, 2020). Therefore, this article takes China as an example to research the talents training related to chemical process safety. The article attempts to answer the following questions:

- What is the current status and what are the existing problems as regards talent training of chemical process safety?
- What is interdisciplinary education and how to apply it to the talent training of chemical process safety?
- What should be the training goals for developing talents in chemical process safety?
- How to build a talent training model related to chemical process safety based on interdisciplinary education, and what are its characteristics?

2. Approach for developing a talent training model of chemical process safety

A systematic approach is developed to construct the talent training model related to chemical process safety, including three steps, as illustrated in Fig. 1.

2.1. Step 1: analyze the current status and the existing problems of talent training

The first step is to investigate the current status and existing problems of talent training related to chemical process safety. The investigation in this step consists of two parts. The first part analyzes the current status of talent training related to chemical process safety in different countries. Take China as an example, the second part analyzes the existing problems of talent training related to chemical process safety. The data and information used in the investigation are mainly obtained from published journal articles, and official websites of organizations related to chemical

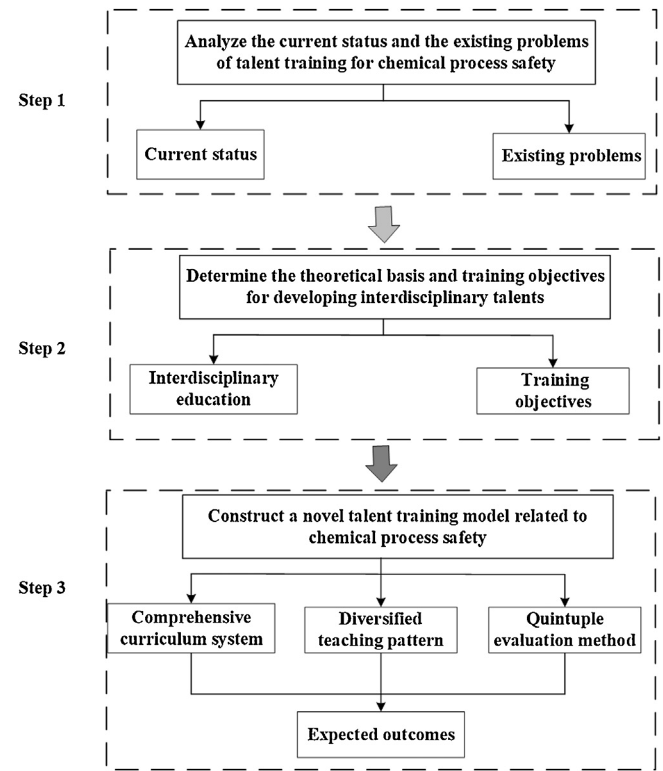

Fig. 1. A systematic approach for constructing the talent training model related to chemical process safety.

process safety. The details and results of step 1 are further explained in Section 3.

2.2. Step 2: determine the theoretical basis and training objectives for developing interdisciplinary talents

Step 2 aims to determine the theoretical basis and training objectives for developing interdisciplinary talents in chemical process safety. We summarized the connotation and elements of interdisciplinary education theory and applied it to the talent training of chemical process safety. Furtherly, we proposed the training objectives of interdisciplinary talents in chemical process safety. The results of Step 2 are illustrated in Section 4.

2.3. Step 3: construct a novel talent training model related to chemical process safety

Step 3 establishes a new talent training model for chemical process safety in China, which includes three parts: (i) a comprehensive curriculum system, (ii) a diversified teaching pattern, (iii) a quintuple evaluation method. The characteristics of each part and expected outcomes of the talent training model are discussed in Section 5.

3. The current status and existing problems of talent training

3.1. The current status and characteristics of talent training

The prosperous development of the chemical industry has led to many accidents. Over the past years, chemical process safety education has been formed and developed to meet the demand for preventing chemical accidents (Lee et al., 2016). From the explosion accident at a chemical plant in Ludwigshafen, Germany in 1921, to the chemical pollution accident at Seveso in Italy in 1976, as well as the poison gas leakage accident at Bhopal in India in 1984, chemical process safety education always drew lessons from these most influential accidents and gradually developed. The safety level of the chemical process industry in some developed countries has dramatically improved, and chemical process safety education has made significant progress (Mkpat et al., 2018). This research found that the talent training related to chemical process safety in various countries has the following two characteristics: (i) offering professional courses related to chemical process safety, (ii) establishing a systematic education model for chemical process safety.

3.1.1. Offering professional courses

Many universities in various countries have set up professional courses related to chemical process safety. However, the professional courses offered by different countries or universities have their specific characteristics.

In the United States, universities, including Georgia Institute of Technology, Texas A & M University, Pennsylvania State University, West Virginia University, Texas Tech University, all offer undergraduates professional courses related to chemical process safety, such as *risk analysis in safety engineering*, *chemical process safety and the environment*, *process safety engineering* (Dee et al., 2015).

In Australia, for example, the University of Melbourne provides a *process safety case study* course for undergraduates, and undergraduates are required to research and present a safety case study (Shallcross, 2013).

In Europe, for instance, "process safety" is set up in the master's course of safety engineering at the University of Leuven, Belgium, focusing on process safety and quantitative risk assessment of representative chemical units, such as reactors, distillation towers, boilers. The German Chemical Engineering and Biotechnology Association stipulates that the "factory and process safety" education should be implemented in both undergraduate, master, and Ph.D. courses. Among them, undergraduates must take a total of 28 h of professional courses, including *safety and risk management*, *safety evaluation of chemical reaction and hazardous material*, *safety instrumented system*, *fire and explosion prevention* (Schmidt, 2013). In the United Kingdom, the institution of Chemical Engineers (IChemE) certification guide lists process safety as a critical knowledge that chemical engineering graduates need to master. Both the University College London, Newcastle University, and the University of Sheffield have set up bachelor's and master's degree courses related to chemical process safety, including *hazard identification*, *risk analysis and evaluation*, *hazard and operability analysis*, *protection layer analysis*, *process safety and loss prevention* (Liu and Wang, 2015). In France, the National Nancy Advanced Institute of Chemical Industry, the National Advanced Institute of Chemical Process Technology Engineers, and the National Advanced Institute of Industrial Technology provide professional courses for undergraduates and masters, such as *hazard and operability analysis*, *failure mode and consequence analysis* (Perrin and Laurent, 2008). Besides, universities in Norway, Sweden, Russia, and Spain also offer professional courses related to chemical process safety and offer bachelor and master degree awards in chemical process-related majors (Amin et al., 2019).

In China, the chemical process safety major in universities is mainly a branch of safety engineering. The number of higher education institutions that have a chemical process safety related major/program in China from 1975 to 2016 is shown in Fig. 2. As shown in the figure, developing talents related to chemical process safety in China began in the 1990s; in the 21 st century, it has developed by leaps and bounds. Among the higher education institutions that have a chemical process safety related major/program in China, Tsinghua University has added the "engineering ethics concept" in the talent training of chemical process safety, and the teaching process emphasizes the importance of practicing and integrates safety related practical projects into daily learning (Du et al., 2015). The China University of Petroleum has founded a major in chemical safety engineering and began enrolling students in 2018. Its training curricula include *chemical safety instrumentation*, *chemical equipment safety*, *chemical process thermal safety risk assessment*, and other courses related to chemical process safety. The South China University of Technology (SCUT) has carried out a lot of educational activities related to chemical process safety in recent years. In 2018, SCUT offered training courses for front-line safety managers of enterprises, such as *chemical production process safety*, *chemical process safety design*. Furthermore, SCUT has invited international experts of chemical process safety to give annual lectures for the students, which actively promoted talent training related to chemical process safety.

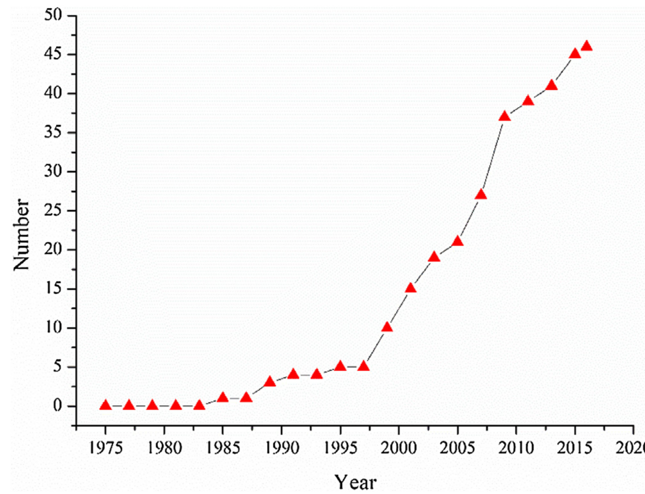

Fig. 2. The number of higher education institutions that have a chemical process safety related major/program in China from 1975 to 2016.

3.1.2. Establishing a systematic education model

The American Society of Chemical Engineers (AIChE) launched a Safety and Chemical Engineering Education (SACHE) project in 1985. This project still exists and has developed into a relatively systematic education model related to chemical process safety (Louvar and Hendershot, 2003). Furthermore, Mkpat et al. (2018) divided process safety education model into three parts: (i) university-based teaching, including undergraduate and postgraduate research; (ii) professional education, including internships and industry-based research; (iii) training for government regulatory agencies.

3.2. The existing problems of talent training

From the analysis in the previous section, it can be found that chemical process safety education has received enough attention in some developed countries. However, the talent training of chemical process safety in China is still in the initial construction stage, the existing problems of talent training related to chemical process safety in China are the following:

- The curriculum system is not interdisciplinary, and a diversified curriculum system has not yet been formed.
- The teaching pattern is relatively simple, and the practice link remains weak.
- The evaluation method focuses on "theory", and the evaluation standard lacks flexibility.

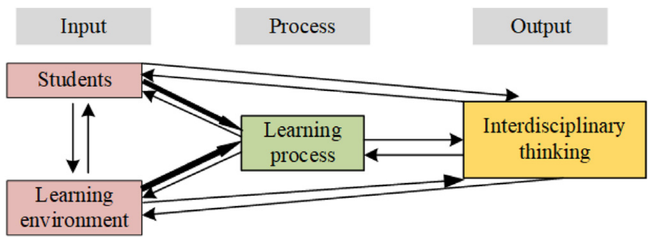

Fig. 3. An interdisciplinary education process model (Zhang et al., 2020).

4. The design of a novel talent training model related to chemical process safety

4.1. Interdisciplinary education

Interdisciplinary education refers to the integration of the concepts, methods, and theories of two or more disciplines to promote understanding or solving complex problems in a single discipline (Warren, 2006). The critical feature of interdisciplinary is the integration of knowledge from different disciplines. This form of "Integrity" can enhance learning outcomes (Lana et al., 2002). Lattuca et al. (2004) conducted empirical research on the results of interdisciplinary learning, confirming that interdisciplinary knowledge can cultivate students' cognition skills. Some scholars define the learning outcomes of interdisciplinary education as interdisciplinary thinking and believe that interdisciplinary thinking gives students the ability to integrate knowledge in different disciplines (Siedlok and Hibbert, 2014; Spelt et al., 2009). Zhang et al. (2020) proposed an interdisciplinary education process model, which is composed of: students, interdisciplinary thinking, learning environment, and learning process, as shown in Fig. 3. Therefore, the concept of interdisciplinary education can be summarized as follows: an educational activity that cultivates innovative talents with systematic knowledge, high-level thinking, and cross-industry capabilities through a series of interdisciplinary teaching and learning. The ultimate goal of interdisciplinary education is to train students to use interdisciplinary thinking to solve complex problems.

There are numerous interdisciplinary programs in engineering education. Some interdisciplinary programs implemented in high schools focus on nanotechnology (Bagaria et al., 2011), chemical engineering (Hanesian et al., 2004), information technology (Rursch et al., 2010), robotics (Verner and Ahlgren, 2002), and electro-optics (Gero and Zach, 2014). Some interdisciplinary programs are implemented for undergraduate students, such as the program of science and engineering education developed by the Israel Institute of Technology (Gero, 2017), and the Safety and Chemical Engineering Education (SACHE) program launched by the Center for Chemical Process Safety (CCPS) of the American Institute of Chemical Engineers (AIChE) (Louvar and Hendershot, 2003).

Some researches have shown that interdisciplinary education can bring a lot of advantages. For instance, students studying in interdisciplinary programs exhibit improved academic performance (Nugent et al., 2010), improved attitudes towards science and engineering (Hirsch et al., 2006), a better understanding of a certain subject (Gero, 2013), and increased motivation to continue with more advanced studies in the subject (Gero, 2016, 2013; Gero and Zach, 2014). Furthermore, interdisciplinary education will contribute to developing a student's cognitive skills, such as flexible thinking (Gero, 2017), critical thinking (Field et al., 2006), systems thinking (Gero and Zach, 2014), and higher-order thinking (Gero, 2016).

At the same time, there are also some challenges in developing and implementing interdisciplinary education. Firstly, there is a need to overcome the students' natural tendency to be satisfied with disciplinary contents and ignore the interaction (Gero, 2013). Secondly, teachers who teach an interdisciplinary course must deal with teaching a discipline or disciplines they have not been trained to teach (Mccomas and Wang, 1998). Thirdly, interdisciplinary teaching needs to balance interdisciplinary aspects and depth of disciplinary content (Gero, 2017). Besides, Neumann et al. (2017) and Perrin et al. (2018) claimed that interdisciplinary education may increase the workload for the students.

In light of the aforesaid, it can be deduced that the development and realization of interdisciplinary education involve significant challenges and not all interdisciplinary programs can be implemented successfully. Spelt et al. (2009) reviewed the conditions needed for the success of interdisciplinary programs: a syllabus that balances the interdisciplinary and disciplinary components; pay attention to patience, curiosity, and openness of the students; and encourage students to teach as part of the teaching team.

Our study applies the concept of interdisciplinary education to the talent training for chemical process safety in China, determines the training goals for developing talents, and constructs a new talent training model related to chemical process safety.

4.2. Training objectives

According to the Engineering Education Certification Work Guide in China (China Engineering Education Accreditation Association Secretariat, 2018), the training objectives are defined as the overall description of the occupational and professional achievements that graduates can achieve about 5 years after graduation, and the training objectives formulated should meet the needs of social development and the teaching-learning orientation of the university. As mentioned in Section 1, the chemical industry is developing rapidly in China, but there is a shortage of talents for chemical process safety, so there is an urgent social need to cultivate chemical process safety talents. And the teaching-learning orientation of SCUT is to cultivate innovative talents with comprehensive knowledge, core capabilities, and a global vision. Besides, according to the literature research, García-Fayos et al. (2020) and Shallcross (2013) provided a list of themes that chemical engineers should master and should apply to resolve safety issues in the chemical industry.

In view of the above, the established talent training model is based on interdisciplinary education, which integrates discipline knowledge of chemical engineering and safety engineering. The training objectives for chemical process safety talents include having students to: (i) familiarize with safety policies and regulations; (ii) obtain basic and professional knowledge of chemical engineering and safety engineering; (iii) master the theories and methods of chemical process safety engineering and management; (iv) possess knowledge of multiple disciplines including chemical technology, safety technology, safety management; (v) acquire an excellent engineering practice ability; (vi) form innovative awareness and global vision.

These training objectives formulated are in line with the Engineering Education Certification Work Guide in China (China Engineering Education Accreditation Association Secretariat, 2018), and also incorporate the recommendations of García-Fayos et al. (2020) and Shallcross (2013).

4.3. The framework of the established talent training model

The talent training model at the university level is mainly composed of curriculum setting, teaching methods, and evaluation methods (Dong, 2012). Based on the talent training goals and concept of interdisciplinary education, we construct an overall framework of the talent training model related to chemical process

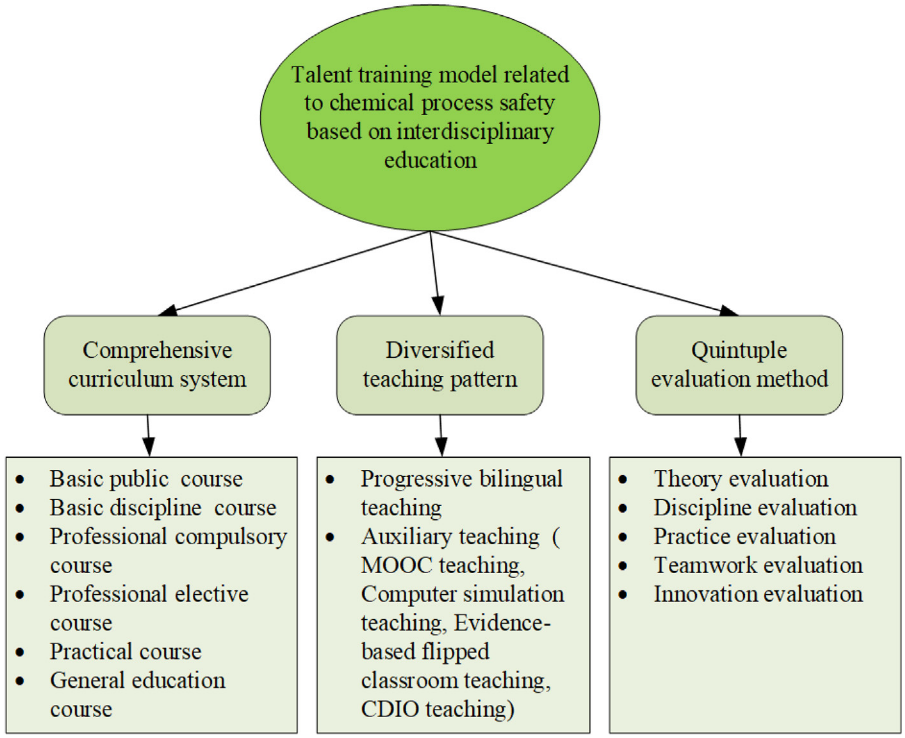

Fig. 4. The framework of the talent training model related to chemical process safety.

safety, which consists of three parts: (i) a comprehensive curriculum system, (ii) a diversified teaching pattern, and (iii) a quintuple evaluation method, as illustrated in Fig. 4.

The curriculum system is the first part of the talent training model. Jiang et al. (2012) divided the curriculum system of safety engineering into three categories: basic course, basic discipline course, and professional course. In this paper, according to the nature of the course, the curriculum of talent training model related to chemical process safety are divided into six categories: (i) basic public course (e.g. *Calculus*, *organic chemistry*, etc.) ; (ii) basic discipline course (e.g. *safety system engineering*, *Chemical process system engineering*, etc.) ; (iii) professional compulsory course (e.g. *chemical process safety*, *chemical safety risk assessment*, etc.) ; (iv) professional elective course (e.g. *safety economics*, *fracture and failure analysis*, etc.); (v) practical course (e.g. course practicum, experiment, etc.); and (vi) general education course (e.g. course-related to humanities, social sciences, science and technology).

To meet one of the conditions for the success of an interdisciplinary program is balancing the interdisciplinary and disciplinary components, in the established comprehensive curriculum system, courses such as *organic chemistry, inorganic chemistry, mass transfer and separation engineering, fluid mechanics and heat transfer*, are offered to ensure that students master basic and professional knowledge of chemical engineering; and courses such as *safety systems engineering*, *engineering mechanics*, *safety management*, *safety ergonomics*, are offered to ensure students master the basic and professional knowledge of safety engineering; besides, courses such as *chemical process safety*, *chemical safety risk assessment*, *chemical safety process design*, are offered to ensure the teaching of interdisciplinary components.

What's more, to meet another condition for the success of an interdisciplinary program needs to pay attention to patience, curiosity and openness of the students, the established comprehensive curriculum system is relatively flexible. After students have mastered the necessary basic and professional knowledge related to chemical process safety, students can take optional professional elective courses and general education courses that they are interested in.

The second part of the talent training model is the teaching pattern. To solve the problem of "the existing teaching pattern is relatively simple" mentioned in Section 3.2, we developed a diversified teaching pattern, which is composed of progressive bilingual teaching and various auxiliary teaching methods. And the auxiliary teaching methods include MOOC teaching, computer simulation teaching, evidence-based flipped classroom teaching, and CDIO teaching. These teaching methods are commonly used in engineering education, and the positive learning outcomes of these teaching methods have been proven in the existing literatures (Deng et al., 2019; Donovan et al., 2018; García-Fayos et al., 2020; Haavi et al., 2018; Mkpat et al., 2018), hence the methodology will help to achieve the training objectives of the established talent training model and improve the teaching-learning effects.

Moreover, among the diversified teaching patterns, the evidence-based flipped classroom teaching and CDIO teaching will encourage the exchange of roles between teachers and students, and promote cooperative teaching between students. Hereby, one of the conditions for the success of an interdisciplinary program which is encouraging students to teach as part of the teaching team is also met.

The third part of the talent training model is the evaluation method. Evaluation is a critical aspect of talent training, and courses with no assessment do not receive the best effort from students (Pitt, 2012). Barrio et al. (2015) have confirmed that assessment is the easiest way to acquire the necessary skills, which can help to improve the performance and the results of learning by the students. Practice, innovation, and teamwork are essential employability skills for chemical engineers (Fletcher et al., 2016; Reedy et al., 2020). Observing the teaching-learning discipline (e.g. attending class on time, submitting homework on time, completing the examination independently, etc.) is also significant to meet the training objectives. Therefore, to overcome the shortcomings of the existing evaluation method and make a more comprehensive eval-

Table 1
The curriculum system of the talent training model for chemical process safety in China.

Curriculum category	Curriculum content
Basic public course	University English; Calculus; Linear algebra and analytic geometry; Probability theory and mathematical statistics; Descriptive geometry and mechanical drawing; University physics; Organic chemistry, inorganic chemistry; Computer technology; C language programming; Freshman seminar; Ideological and political theory
Basic discipline course	Engineering mechanics; Fire and explosion prevention technology; Circuits and electronics; Fluid mechanics and heat transfer; Mass transfer and separation engineering; Safety system engineering; Chemical process system engineering; Principles of safety science; Safety management; Safety ergonomics; Principles of chemical engineering
Professional compulsory course	Chemical process safety; Chemical instrumentation and automation; Chemical safety process design; Chemical safety risk assessment; Occupational health; Chemical technology
Professional elective course	Public safety and emergency management; Mechanical design basics; Accident investigation and analysis; Safety monitoring and control; Safety economics; Mechanical safety; Electrical safety; Fracture and failure analysis; Safe behavior psychology; Safety engineering industry model and innovation
Practical course	Course practicum; Experiment; Train; Internship; Graduation project
General education course	Course-related to humanities; Course-related to social sciences; Course-related to science and technology

uation of the teaching-learning process, we propose a quintuple evaluation method, namely the five-element radar chart evaluation method, and five elements refer to theory, practice, teamwork, innovation, and discipline.

The established talent training model is designed for undergraduates of chemical process safety engineering. Students who take part in the program should be interested in chemical process safety and have some foundation in mathematics, chemistry, and mechanics. The students' average age is 20 years. Additionally, 12 teachers from the same university will take part in the interdisciplinary program, most of them have a Ph.D. degree in chemical engineering or safety engineering. The teachers' average age is 45 years, and their teaching experience is about 15 years. The duration of this program is four years because the educational system for undergraduates is four years in China.

5. Results and discussion

5.1. A comprehensive course system

5.1.1. The composition of the course system

The course system of the established talent training model related to chemical process safety is illustrated in Table 1. The basic public curriculum focus on cultivating students' basic knowledge of natural sciences, social sciences, and computer technology. The basic discipline courses would help students to master the basic knowledge of safety engineering and chemical engineering. The professional courses, including professional compulsory courses and professional elective courses, would help students to learn the crucial theories and methods related to chemical process safety, which can be used to solve complex engineering problems in the chemical process industry. The practical courses help to improve students' practical ability and deepen their understanding of professional knowledge. For general education courses, students can choose courses related to humanities, social sciences, and technology according to their interests.

5.1.2. The characteristics of the course system

The comprehensive course system of the talent training model has the following characteristics:

(1) Process safety related courses exist as a separate course

In the established curriculum system, process safety related courses (e.g. *chemical process safety*, *chemical safety risk assessment*, etc.) are set up separately. In this strategy, process safety can be taught as a separate full course, and thus the previous drawbacks of the integration of process safety concepts into existing courses (Mkpat et al., 2018; Perrin et al., 2018) described in Section 1 would disappear. Moreover, the talent training of chemical process safety would be more consistent and systematic.

(2) Paying attention to the basic knowledge related to chemical engineering and safety engineering.

In the chemical process industry, there are many risk factors such as high temperature, high pressure, flammability, and toxicity. In order to avoid these risks, students need to master the basic principles of chemical reaction, chemical production processes, and safety engineering. For basic public courses, *organic chemistry* and *inorganic chemistry* are set up to enable students to learn the basic knowledge of chemical reaction. The basic discipline courses such as *safety system engineering*, *chemical process system engineering*, *principles of safety science*, *safety management*, *principles of chemical engineering* can help students master the basic knowledge of chemical engineering and safety engineering.

(3) Setting up more professional courses related to chemical process safety.

Professional compulsory courses, such as *chemical process safety*, *chemical instrumentation and automation*, *chemical safety process design*, *chemical safety risk assessment*, *chemical technology* are set up to cultivate students' professional knowledge and techniques related to chemical process safety. As a flexible module in the curriculum system, the professional elective courses focus on the expansion of the subject knowledge, which involves management, economics, mechanical safety, electrical safety, public safety, etc. Universities can also set up more professional elective courses for students according to their actual needs.

(4) The practical courses are more comprehensive.

The talent training model also focuses on cultivating students' practical ability, therefore, diversified practical courses are established, as shown in Fig. 5. The practical courses consists of five categories: (i) course practicum, so called "course practice", refers to the practicum for mastering the content of a specific course, including the course practicum of *principles of chemical engineering*, *safety ergonomics*, *chemical safety process design*, *chemical safety risk assessment*; (ii) experiment, including experiment of *university physics*, *organic chemistry*, *inorganic chemistry*, *circuit and electronics*, *principles of chemical engineering*, *safety engineering*, *chemical process safety*; (iii) train, consisting of simulation training, refers to using computer simulation technology to simulate the device on and off, hazard identification, HAZOP analysis, accident consequence, and enterprise training, refers to allowing students to enter different chemical companies in groups and get in touch with actual production activities; (iv) internship, consisting of cognitive internship, refers to visiting the working places related to chemical process, and production internship, refers to participating in the chemical production process directly; and (v) graduation project, refers to students choosing a topic related to chemical process safety for research and submitting a research report.

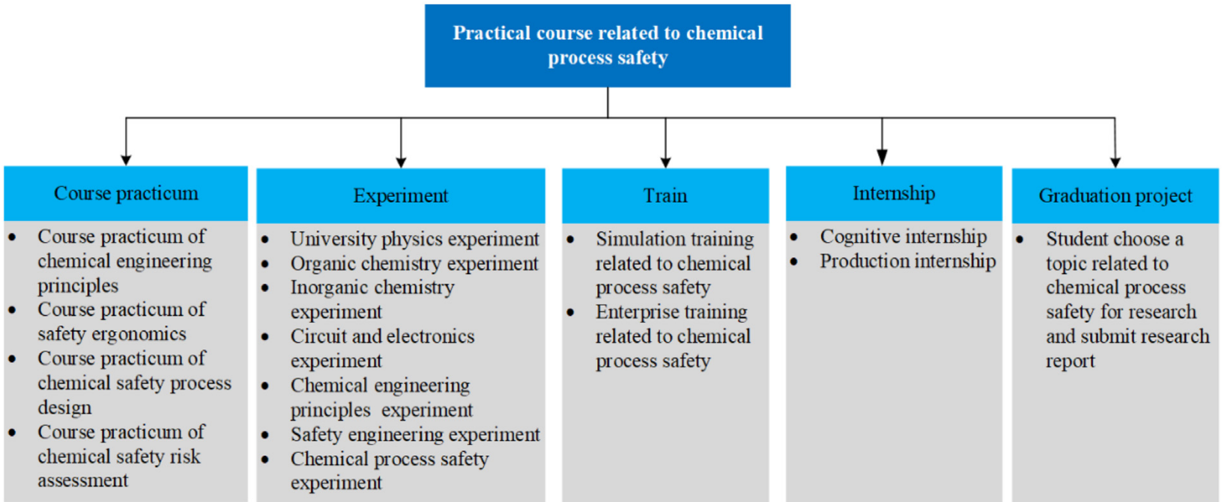

Fig. 5. Practical course related to chemical process safety.

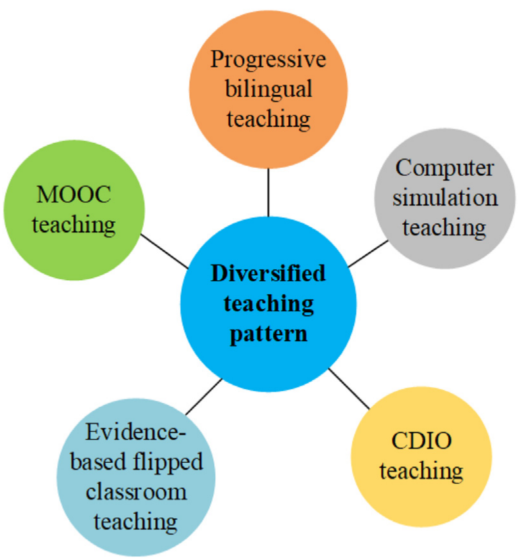

Fig. 6. The composition of diversified teaching pattern.

5.2. A diversified teaching pattern

According to the established curriculum system, our study establishes a diversified teaching pattern based on the progressive bilingual teaching method and that is supplemented by multiple auxiliary teaching methods, as illustrated in Fig. 6. The auxiliary teaching methods include MOOC teaching, computer simulation teaching, evidence-based flipped classroom teaching, and CDIO teaching.

5.2.1. Progressive bilingual teaching method

The bilingual teaching method refers to using two languages as the teaching language, and the second language is not only used as a learning object, but also used as a teaching medium. Some countries have already been using bilingual teaching to carry out teaching activities in different subjects (Cai et al., 2016; Morton, 2012). Our study proposes a progressive bilingual teaching method, which can gradually improve Chinese students' professional English skills. The teaching plan for bilingual courses is shown in Table 2. Progressive bilingual teaching can be divided into three stages: basic bilingual teaching, transitional bilingual teaching, and immersive bilingual teaching. The characteristics of each stage are illustrated in Table 3.

Table 2
Teaching plan of bilingual courses related to chemical process safety.

Applicable Grade	Bilingual courses	Course category
First-year student	Inorganic chemistry; Organic chemistry	Basic public course
Second-year student	Fluid mechanics and heat transfer; Fire and explosion prevention technology; Mass transfer and separation engineering; Chemical process system engineering; Safety system engineering; Principles of chemical engineering	Basic discipline course
Third-year student	Chemical safety process design; Chemical safety risk assessment	Professional compulsory courses
Final year student	Chemical process safety; Chemical technology	Professional compulsory course

5.2.2. Auxiliary teaching methods

(1) MOOC teaching method

MOOC(massive open online course) teaching method has exerted a significant influence on higher learning as it improves education outcomes (Alhazzani, 2020). Therefore, the MOOC teaching method is used for the proposed curriculum system. Some basic courses and professional compulsory courses can use the MOOC teaching method to achieve better learning outcomes. For example, the analysis steps and process of system safety analysis methods such as PHA, FMEA, HAZOP, ETA, FTA in the "safety system engineering"; the operation of chemical process simulation software such as ASCEND and ASPEN PLUS in "chemical process system engineering"; the operation of FLACS, SAFETI, and other risk assessment simulation software in "chemical safety risk assessment". The application of MOOC teaching methods can enable students to learn the content of these courses better and achieve better learning outcomes.

(2) Computer simulation teaching method

The computer simulation teaching method is mainly used in the teaching process of professional courses and "train teaching" related to chemical process safety. It can be combined with classroom teaching and MOOC teaching to stimulate students' learning enthusiasm and cultivate students' ability to operate various simulation software independently. Computer simulation is capable of

Table 3
The characteristics of each stage of the progressive bilingual teaching method.

Stage	Teaching method	Applicable grade	Characteristics
First stage	Basic bilingual teaching	First-year and second-year student	The main content is taught in Chinese, and some critical professional terms and concepts are explained both in Chinese and English
Second stage	Transitional bilingual teaching	Third-year student	Some basic chapters are taught in English, and some difficult chapters involving complex professional knowledge and theories are taught both in English and Chinese
Third stage	Immersive bilingual teaching	Final year student	Instructors and students all use English to complete the course activities and feedback

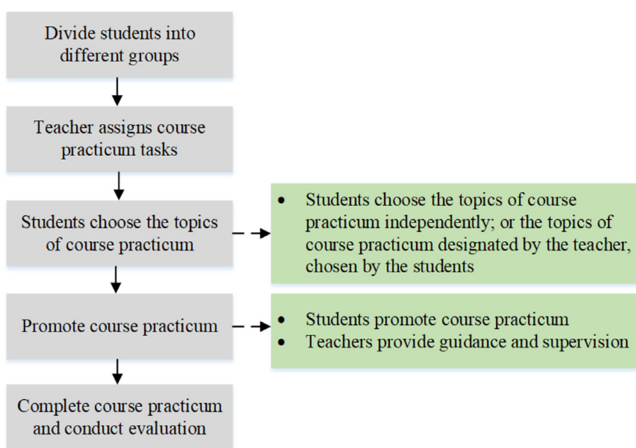

Fig. 7. The teaching process of chemical process safety course practicum based on CDIO.

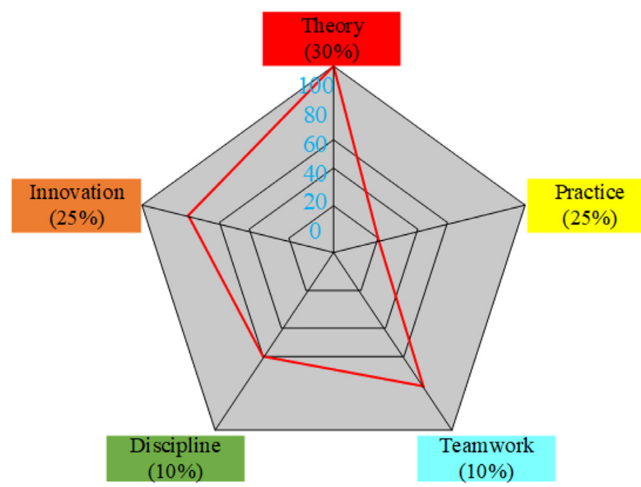

Fig. 8. The quintuple evaluation method——five-element radar chart.

achieving results consistent with experimental research, and has higher safety and lower economic costs.

(3) Evidence-based flipped classroom teaching method

Evidence-based science, so-called “evidence-based practice”, is initially used in the medical community (Wakibi et al., 2020). “Evidence-based” is applied in flipped classroom teaching, which means using the student’s learning data obtained in or out of class as evidence, and carry out teaching in class based on these learning feedbacks. The evidence-based flipped classroom teaching method for chemical process safety is mainly combined with MOOC teaching. Students learn course knowledge on the MOOC platform, and instructors solve the questions encountered by students in the classroom.

(4) CDIO teaching method

CDIO is the abbreviation of conception, design, implementation, and operation. CDIO teaching can cultivate students’ professional technical knowledge, personal ability, teamwork ability, and communication ability through systematic product design (Song, 2018). CDIO teaching method is mainly used in the course practicum related to chemical process safety. The teaching process of the course practicum for chemical process safety based on the CDIO concept is illustrated in Fig. 7.

5.3. A quintuple evaluation method

Evaluation is more than just a course examination of theory, a reasonable evaluation method needs to examine students’ comprehensive ability. A quintuple evaluation method is proposed for developing interdisciplinary talents, also named the five-element radar chart evaluation method, as illustrated in Fig. 8. The five-element radar chart is a two-dimensional data chart composed of five elements, which can intuitively reflect the comprehensive abilities of each student graphically. Five elements refer to theory, practice, teamwork, innovation, and discipline. By entering the score of each element of each course, the instructor can not only get the total score of the course but also intuitively find out the strengths and weaknesses of the five elements in each course of each student. A series of general evaluation radar charts are formed every semester, and the five-element radar chart can intuitively describe the students’ learning condition from five aspects: theory, practice, teamwork, innovation, and discipline. Instructors can comprehensively understand the students’ learning effect of every course, and use the evaluation results further to improve the teaching methods.

The instructor scores each course based on the student’s performance on each element. The course score G can be calculated according to Eq. (1), where L is the theory score, S is the practice score, T is the teamwork score, J is the discipline score, C is the innovation score, and A_L, A_S, A_T, A_J, A_C is the corresponding weights. As shown in Fig. 8, $A_L = 0.3$, $A_S = 0.25$, $A_T = 0.1$, $A_J = 0.1$, $A_C = 0.25$. The weight of each element can also be adjusted appropriately according to the nature of the course.

$$G = L \times A_L + S \times A_S + T \times A_T + J \times A_J + C \times A_C \quad (1)$$

Each element can evaluate the students’ corresponding abilities, which is conducive to cultivating students’ comprehensive ability and innovative thinking related to chemical process safety. The intention and evaluation forms of each element are explained in Table 4.

5.4. Teachers’ and students’ perceptions

Teachers and students of chemical process safety were asked to give their perceptions on the established talent training model. Participation in the survey was voluntary and the responses were anonymous. Using a questionnaire survey form, teachers and stu-

Table 4
The explanation of each element of the quintuple evaluation method.

Element	Description	Forms of evaluation
Theory	Promoting students to master and use basic and professional knowledge	Course exam; Course paper; Course discussion; Homework; Question set; Work display
Practice	Encouraging students to develop practice ability	Experiment report and performance; Experiment examination; Training report and performance; Curriculum practicum report; Computer simulation examination
Teamwork	Fostering students' teamwork sense, enhancing students' team responsibility	Team discussion; Teamwork display; Team experiment exam
Innovation	Encouraging students to develop innovative awareness, students can get extra points based on innovative work	Innovative works, such as proposing innovative content, publishing academic papers related to the course
Discipline	Urging students to develop a good learning habit and behavior	Class discipline and attendance; Homework discipline and submission; Exam discipline (i.e. completing the examination independently and cheating is prohibited)

dents were asked to state the extent to which they agreed or disagreed with a series of statements. The questionnaire uses a five-level Likert scale, in which "1" is assigned to the response "strongly disagree" and "5" is assigned to the response "strongly agree". The responses and the average scores for the teachers and students for the questionnaires are illustrated in Tables 5 and 6.

The teachers which participated all agreed with the statement that the developed talent training model was helpful to accelerate the training talents of chemical process safety. Of the teachers surveyed 83.3 % agreed that the established comprehensive curriculum system can help students master the core knowledge and skills related to chemical process safety, and also agreed that the proposed diversified teaching pattern can arouse students' interest and enthusiasm in learning chemical process safety. More than seventy-seven percent of the teachers either agreed or strongly agreed with the statement that progressive bilingual teaching in the diversified teaching pattern is an effective way to improve the professional English skills of Chinese students. And a similar percentage agreed that using the MOOC teaching method to teach the operation of chemical process simulation software and system safety analysis methods can achieve better teaching-learning effect. More than ninety-four percent of the teachers agreed with the statement that the quintuple evaluation method can evaluate students' learning performance comprehensively. Moreover, Of the teachers 83.3 % either agreed or strongly agreed that the quintuple evaluation method can encourage the development of students' innovative thinking skills and contribute to cultivating creative interdisciplinary talents.

The majority of the students surveyed either agreed or strongly agreed that they were interested in the developed talent training model related to chemical process safety. Of the students surveyed 83.8 % either agreed or strongly agreed with the statement that the developed talent training model related to chemical process safety can improve their employability skills. 71.1 % of the students surveyed mentioned that the established comprehensive curriculum system of chemical process safety helps them to master the core knowledge and skills related to chemical process safety. Over three-fifths of the students either agreed or strongly agreed that the proposed diversified teaching pattern can arouse their interest and enthusiasm in learning chemical process safety. More than seventy-one percent of the students agreed that progressive bilingual teaching in the diversified teaching pattern is helpful to improve their professional English skills. Of the students 78.9 % either agreed or strongly agreed with the statement that using the MOOC teaching method to teach the operation of chemical process simulation software and system safety analysis methods can achieve a better teaching-learning effect. Lastly, over 81 % of the students either agreed or strongly agreed that the quintuple evaluation method can evaluate their learning performance comprehensively.

Table 5
Summary of survey responses. Teachers asked to indicate the extent to which either agreed or disagreed with the following statements using a five-level Likert scale.

Statements	Number of respondents	Strongly disagree(1)	Disagree (2)	Neither agree nor disagree (3)	Agree (4)	Strongly Agree (5)	Average score	Agree (%)	Disagree (%)
The developed talent training model is helpful to accelerate the training talents of chemical process safety	18	0	0	0	1	17	4.9	100.0	0.0
The established comprehensive curriculum system can help students master the core knowledge and skills related to chemical process safety	18	0	0	3	4	11	4.4	83.3	0.0
The proposed diversified teaching pattern can arouse students' interest and enthusiasm in learning chemical process safety	18	0	0	3	9	6	4.2	83.3	0.0
Progressive bilingual teaching in the diversified teaching pattern is an effective way to improve the professional English skills of Chinese students	18	0	0	4	5	9	4.3	77.8	0.0
Using the MOOC teaching method to teach the operation of chemical process simulation software and system safety analysis methods can achieve a better teaching-learning effect	18	0	0	4	6	8	4.2	77.8	0.0
The quintuple evaluation method can evaluate students' learning performance comprehensively	18	0	0	1	9	8	4.4	94.4	0.0
The quintuple evaluation method can encourage development of students' innovative thinking skills and contribute to cultivating creative interdisciplinary talents	18	0	0	3	6	9	4.3	83.3	0.0

Table 6
Summary of survey responses. Students asked to indicate the extent to which either agreed or disagreed with the following statements using a five-level Likert scale.

Statements	Number of respondents	Strongly disagree(1)	Disagree (2)	Neither agree nor disagree (3)	Agree (4)	Strongly Agree (5)	Average score	Agree (%)	Disagree (%)
I am interested in the developed talent training model related to chemical process safety based on interdisciplinary education	38	2	0	10	18	8	3.8	68.4	5.3
The developed talent training model related to chemical process safety can improve my employability skills	37	0	2	4	19	12	4.1	83.8	5.4
The established comprehensive curriculum system of chemical process safety helps me to master the core knowledge and skills related to chemical process safety	38	0	0	11	14	13	4.1	71.1	0.0
The proposed diversified teaching pattern can arouse my interest and enthusiasm in learning chemical process safety	38	1	2	11	14	10	3.8	63.2	7.9
Progressive bilingual teaching in the diversified teaching pattern is helpful to improve my professional English skills	38	0	2	9	16	11	4.0	71.1	5.3
Using the MOOC teaching method to teach the operation of chemical process simulation software and system safety analysis methods can achieve a better teaching-learning effect	38	0	0	8	20	10	4.1	78.9	0.0
The quintuple evaluation method can evaluate my learning performance comprehensively	38	0	0	7	16	15	4.2	81.6	0.0

From the above, it can be found that the responses of teachers and students is very positive to the developed talent training model based on interdisciplinary education.

5.5. Expected outcomes

SCUT is one of the earliest higher education institutions that have a chemical process safety related major/program in China. In recent years, a series of measures have been taken to accelerate the talent training related to chemical process safety in SCUT, such as promoting the reform of the curriculum system (SCUT, 2017), developing teaching pattern (e.g MOOC, Flipped classroom teaching, etc.), offering training courses for front-line safety managers of enterprises (People's Government of Guangdong Province, 2018), etc. Therefore, SCUT has laid a good foundation for the application of the constructed talent training model related to chemical process safety. The talent training model related to chemical process safety established in this article is expected to achieve the following outcomes:

- Establish a comprehensive course system. Based on interdisciplinary education, the course system enables students to master the professional knowledge of chemical engineering and safety engineering at the same time, and broaden students' horizons by taking professional courses and general courses that interest them.
- Form a diversified teaching pattern based on progressive bilingual teaching and that is supplemented by multiple auxiliary teaching methods. The teaching pattern will improve students' professional English ability, which contributes to building an international communication and cooperation mechanism in the field of chemical process safety.
- Construct a quintuple evaluation method. The quintuple evaluation method can evaluate students' abilities comprehensively, encourage and develop students' innovative thinking skills, and contribute to cultivating creative interdisciplinary talents.
- Improve the quality of talent training in the chemical process industry and developing talents related to chemical process safety for government agencies, social enterprises, safety intermediaries, and other institutions.
- Work as a reference for other universities that want to establish or improve chemical process safety related majors around the world.

6. Conclusions

In the present study, we develop an approach for constructing a talent training model of chemical process safety at the university level. The approach includes three steps: (i) analyze the current status and the existing problems of talent training for chemical process safety; (ii) determine the theoretical basis and training objectives for developing interdisciplinary talents; (iii) construct a novel talent training model related to chemical process safety.

Besides, this study establishes a novel talent training model related to chemical process safety used the proposed approach which consists of a comprehensive curriculum system, a diversified teaching pattern, and a quintuple evaluation method. The comprehensive course system includes six modules: basic public course, basic discipline course, professional compulsory course, professional elective course, practical course, and general education course. The diversified teaching pattern is proposed with progressive bilingual teaching method as the mainstay, supplemented by multiple teaching methods such as MOOC teaching, computer simulation teaching, evidence-based flipped classroom teaching, and CDIO teaching. The quintuple evaluation method consists of five essential elements: theory, practice, teamwork, innovation, and discipline.

Although the research in this article takes China as an example, which has the most abundant chemical industry in the world, the results can also provide a guidance for other countries with rapidly developing chemical industry to improve the safety and sustainability of the chemical industry worldwide. It should be pointed out that developing talents for chemical process safety is a long-term process. The talent training model also proposes higher requirements for the teaching staff in universities. Therefore, it is necessary to strengthen the construction of professional educators. The government, universities, and enterprises need to pay more attention and work together to accelerate talent training of chemical process safety and improve the safety level of the chemical industry.

Declaration of Competing Interest

The authors report no declarations of interest.

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