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Developing an integrated education-practice-incubation-entrepreneurship framework for innovative talent development in petroleum engineering

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Abstract: Driven by China's "dual carbon" goals, the energy sector is moving rapidly toward low-carbon, green, and intelligent development. These changes are reshaping the knowledge structure and competency requirements of petroleum engineering graduates, while conventional training models are becoming less able to respond to emerging industry needs. Against this background, the Petroleum Engineering program at Southwest Petroleum University has carried out a systematic reform of its talent development model, drawing on the advantages of its national key discipline and national first-class undergraduate program. The reform also responds to national energy security priorities and the development needs of the Chengdu-Chongqing economic region. Guided by Emerging Engineering Education and the principle of fostering virtue through education, the program reorganized the training process and established an integrated "education-practice-incubation-entrepreneurship" system. The system brings together ideological and political education, curriculum reform, engineering practice, and innovation and entrepreneurship education, and connects theoretical learning, practical training, research participation, and industrial application within a continuous development pathway. Professional education is therefore linked more closely with values education, classroom learning with engineering practice, and research outcomes with innovation and commercialization. The implementation of this model has contributed to the development of students' engineering competence, innovative thinking, and entrepreneurial ability, while offering a practical approach that may inform talent development in petroleum engineering and related energy disciplines.

1. Introduction

Petroleum engineering is closely related to national energy security, and the quality of talent training in this field has a direct bearing on the transformation of the oil and gas industry and the sustainable development of the energy sector. As an interdisciplinary engineering discipline, petroleum engineering draws on geology, mechanics, chemistry, physics, and related fields to address key issues in the safe and efficient development of subsurface oil and gas resources, including reservoir fluid flow, production pathway construction, and hydrocarbon recovery enhancement. In China, petroleum engineering was formally established as an undergraduate major in 1998 through the integration of reservoir engineering, production engineering, and drilling engineering, and it is currently classified under the Mining Engineering category with the major code 081502. With the advancement of China's "dual carbon" goals, the oil and gas industry is undergoing a transition toward low-carbon, green, and intelligent development (Shields et al., 2014; Ruiz-Rivas et al., 2020). At the regional level, the Chengdu-Chongqing economic region is also promoting the development of a natural gas production base with an annual capacity of 100 billion cubic meters. These changes have raised new expectations for petroleum engineering graduates. In addition to a solid foundation in professional knowledge and engineering skills, students are increasingly required to possess interdisciplinary competence, the ability to solve complex engineering problems, innovation and entrepreneurial awareness, and a strong sense of professional responsibility, particularly in relation to energy development in western China and national energy security.

Engineering education has gradually moved beyond a purely content-driven approach, with greater attention being given to student learning outcomes and competency development. Within this shift, constructive alignment and outcome-based education (OBE) stress the need to coordinate intended learning outcomes with curriculum design, teaching activities, and assessment (Biggs, 1996; Felder and

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Brent, 2003; Mahrishi et al., 2025). A range of teaching approaches, including active learning, inductive teaching, project-based learning, and experiential learning, have been introduced to improve students' ability to solve problems and apply disciplinary knowledge in engineering settings (Prince, 2004; Prince and Felder, 2006; Jamison et al., 2022; Lavado-Anguera et al., 2024; Ramírez de Dampierre et al., 2024). In parallel, work-integrated learning and university-industry collaboration have become important means of exposing students to professional practice and strengthening employability-related competencies (Jackson, 2015; Trevelyan, 2019; Jackson and Dean, 2023; Shah and Gillen, 2024; Vuoriainen et al., 2025; Hwang et al., 2026). Entrepreneurship education has also received growing attention because it provides a way to connect engineering knowledge with innovation, technology transfer, and value creation (Täks et al., 2014; Nabi et al., 2017; Huang-Saad et al., 2018; Browning and Bustard, 2024). In petroleum and energy engineering, sustainability concerns and the ongoing energy transition have further prompted curriculum renewal and broader competency requirements (Shields et al., 2014; Ruiz-Rivas et al., 2020). Despite these developments, professional education, engineering practice, research incubation, and entrepreneurship are still commonly treated as separate components. Less attention has been given to how these elements can be connected within a continuous talent development pathway for petroleum engineering. To address this issue, this study develops and implements an integrated "education-practice-incubation-entrepreneurship" framework at Southwest Petroleum University.

The Petroleum Engineering program at Southwest Petroleum University is a major center for petroleum engineering education in China. Supported by a national key discipline and a national first-class undergraduate program, it has a solid foundation for talent development. Beyond professional training, the program also places strong emphasis on cultivating graduates with a clear sense of social responsibility. In response to changes in the oil and gas industry and the growing demand for new engineering talent, the training model has been progressively adjusted. Reform efforts have focused on a problem- and demand-oriented approach, the integration of ideological and political education throughout the training process, closer alignment between the curriculum and industry needs, and stronger university-industry collaboration in practical education. Greater attention has also been given to translating student innovation and research outcomes into practical applications and entrepreneurial activities. Building on these efforts, the program established an integrated "education-practice-incubation-entrepreneurship" talent development system to better connect student development with the evolving needs of the industry.

2. Conceptual framework

The "education-practice-incubation-entrepreneurship" system is an integrated approach to innovative talent development guided by the principles of OBE. It connects education, industry, research, and practical application within a coordinated training process. Moral and values education form the foundation, while professional education provides the core disciplinary knowledge needed for subsequent development. Engineering practice then creates opportunities for students to apply this knowledge in real-world contexts. Innovation incubation serves as a link between research, creative ideas, and practical outcomes, whereas entrepreneurship extends these outcomes toward wider application and commercialization. In this way, the four components form a continuous pathway from knowledge acquisition and competency development to innovation and the practical application of research outcomes (Biggs, 1996; Felder and Brent, 2003; Mahrishi et al., 2025).

The education component serves as the starting point of the system by developing students' values and disciplinary knowledge. General and professional education are integrated throughout the curriculum, with ideological and political education embedded in the learning process. Rather than treating knowledge acquisition and values education as separate tasks, the program combines the two within professional training. This helps clarify both the type of graduates the program seeks to cultivate and the knowledge structure and theoretical grounding they are expected to develop, providing a basis for later stages of professional and practical training.

The practice component extends classroom learning into real engineering settings, where students are expected to apply disciplinary knowledge to practical problems. Through university-industry collaboration, the program has established a progressive training process that combines simulation-based learning with internships in industrial environments. Exposure to these settings allows students to engage with complex engineering tasks and develop their problem-solving abilities through practice. It also helps bridge the gap between theoretical learning and engineering application by turning classroom knowledge into practical skills (Jackson, 2015; Jamison et al., 2022; Hwang et al., 2026).

The incubation component connects learning with research and practical application. Its main role is to strengthen students' innovation capability by making better use of research resources and support platforms. Key laboratories, engineering centers, and industrial colleges provide the settings in which students can participate in research and develop their ideas further. By bringing research resources into the training process, these platforms help students move from initial ideas to technically feasible prototypes and, where possible, toward practical application.

The entrepreneurship component extends innovation beyond the university by creating pathways for practical application and commercialization. Entrepreneurship education, professional mentoring, and financial support provide students with the resources needed to develop research and technological outcomes into products, services, or new ventures. In this process, innovation is connected more directly with industrial and market needs, while students gain a clearer understanding of how engineering knowledge can create value beyond the academic setting (Täks et al., 2014; Nabi et al., 2017; Huang-Saad et al., 2018).

As illustrated in Fig. 1, the four components are closely connected throughout the training process, linking education and engineering practice with innovation incubation and entrepreneurship. This structure helps connect theory

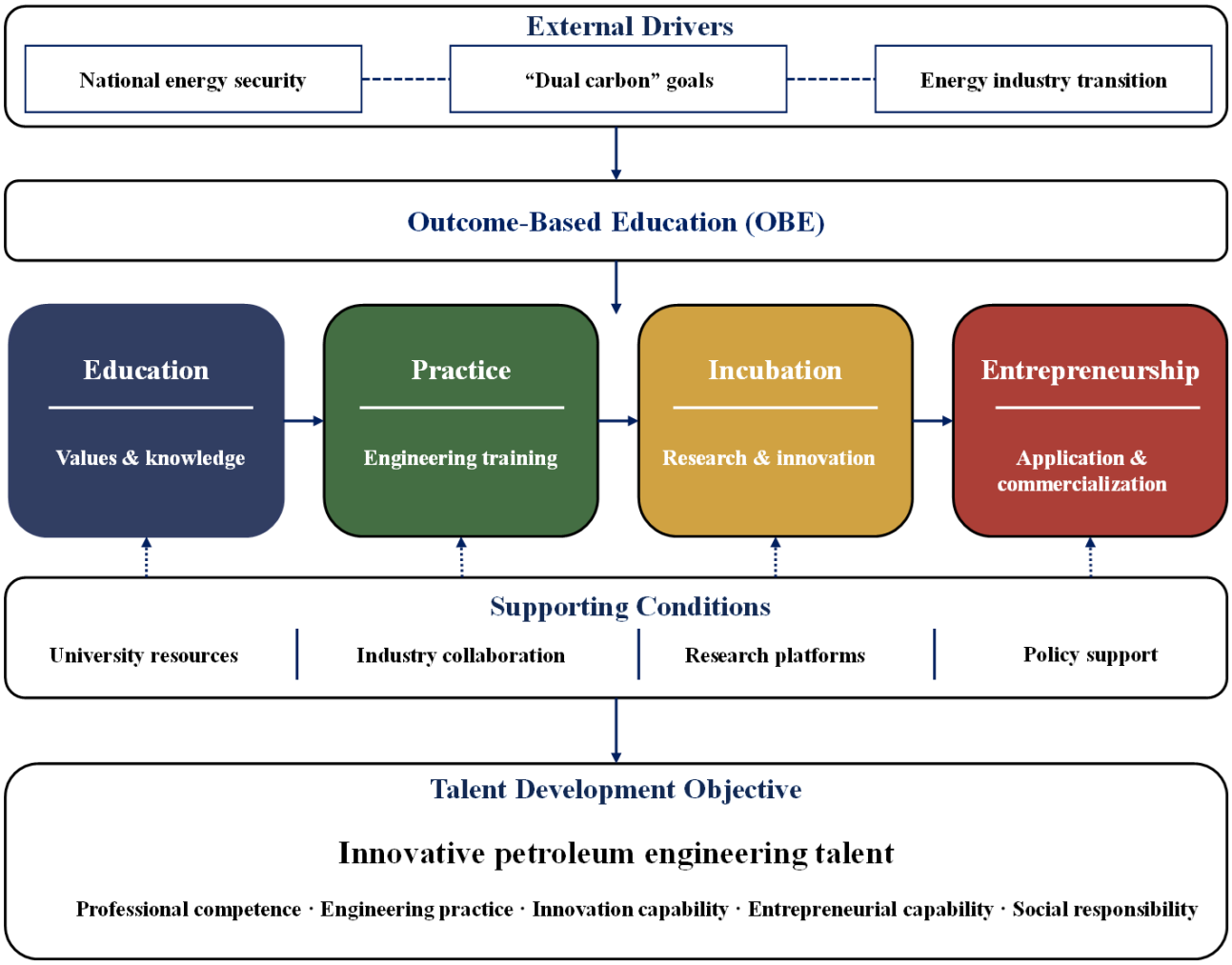


Figure 1 Integrated framework for petroleum engineering talent development

with practice, teaching with research, and university education with industry needs. Supported by university resources, industry partners, and related platforms, the system brings together knowledge development, engineering training, innovation, and entrepreneurship within a coordinated process. Rather than relying mainly on one-way knowledge transfer, the framework places greater emphasis on competency development and the practical application of learning outcomes.

3. Implementation of the "Four-in-One" framework

3.1 Values-based education

Moral and values education is embedded throughout the talent development process in the Petroleum Engineering program. Drawing on the Daqing Spirit, the Iron Man Spirit, and Southwest Petroleum University's long-standing commitment to national energy development, the program incorporates ideological and political education into both classroom teaching and complementary online and extracurricular activities. These elements are used to reinforce students' professional identity and sense of responsibility. Building on this practice, the program developed the "Three Integrations and Four Approaches" model for curriculum-based ideological and political education, bringing values education, professional knowledge, and competency development into a more coordinated learning process.

3.1.1 Three integrations in education

The program integrates moral values, professional ethics, and engaging learning activities into professional education. Course design goes beyond technical knowledge alone by incorporating themes such as national energy responsibility, patriotism, engineering ethics, and professional dedication. In courses related to oil and gas field development, for example, students are introduced to the experiences of earlier generations of petroleum engineers who worked under difficult conditions to support China's energy development. Linking these historical and professional examples with disciplinary content allows ideological and political education to be incorporated more naturally into the learning process.

3.1.2 Four approaches to teaching

To make ideological and political education more closely connected with professional teaching, the program uses concepts, principles, visual materials, stories, and role models that arise naturally from course content. Topics in seepage mechanics and rock mechanics, for example, are discussed alongside real engineering cases from oil and gas fields and major scientific and technological projects. Classroom teaching also draws on the experiences

of outstanding alumni who have worked in western China and contributed to technological innovation. By placing these materials within disciplinary contexts, values education is incorporated into professional learning in a more natural and engaging way.

3.1.3 Online platform for ideological and political education

In response to the growing use of new media in education, the program established an online learning network under the theme of "Energy for the Nation." The network includes initiatives such as the "Micro-Classroom for Party History Education" and the "Oil and Gas Elite Lecture Hall," with support from a nationally recognized Yi Ban workstation. These activities extend ideological and political education beyond the classroom and create more opportunities for interaction between teachers and students. With support from industry partners, the program has also introduced scholarships related to natural gas development and used competitions and awards to encourage student participation. These practices contributed to the recognition of the Petroleum Engineering program as a provincial-level demonstration program for curriculum-based ideological and political education.

3.2 Curriculum and teaching reform

Curriculum reform has been guided by changes in the oil and gas industry and the growing demand for low-carbon, green, and intelligent development. Supported by the "One Alliance, Two Schools" platform, including the PetroChina-Southwest Petroleum University Innovation Alliance, the School of Petroleum and Natural Gas Engineering, and the Natural Gas Modern Industry College, the program has revised its curriculum in line with the principles of OBE. The revised curriculum maintains balanced coverage of oil and gas engineering while placing greater emphasis on natural gas, helping course content remain responsive to changes in the energy industry (Shields et al., 2014; Ruiz-Rivas et al., 2020).

3.2.1 Optimizing the core curriculum system

To meet the growing demand for natural gas development in the Chengdu-Chongqing economic region, the program has placed greater emphasis on natural gas while retaining its established strengths in petroleum engineering. Natural Gas Engineering was introduced as a core course alongside Reservoir Engineering, Drilling and Completion Engineering, and Oil Production Engineering, forming a four-course foundational structure. The curriculum was further expanded through comprehensive courses such as Petroleum and Natural Gas Geology and Oil and Gas Production Engineering Design, together with interdisciplinary electives including Oil and Gas Reservoir Management. Taken together, these courses provide broad coverage of geology, drilling, reservoir development, production, gathering, and utilization, while maintaining a balanced treatment of oil and gas engineering.

3.2.2 Updating textbooks and teaching content

High-quality teaching materials are an important part of maintaining the relevance of professional courses. Faculty members in the program have participated in the preparation and revision of nationally planned undergraduate textbooks, including Underground Oil and Gas Seepage Mechanics (3rd ed.) and Well Testing Analysis (2nd ed.). During these revisions, recent developments in unconventional oil and gas engineering, such as shale gas and tight gas seepage theory, together with carbon capture, utilization and storage (CCUS), were incorporated into both the textbooks and related classroom teaching. Regular updates of this kind help ensure that course content keeps pace with technological advances in the oil and gas industry.

3.3 Practice-oriented education

Practice is a core element of engineering education. Drawing on its long-term cooperation with industry, the program has developed a collaborative training model organized around the "Three Collaborations and Three Integrations." The "Three Collaborations" involve joint planning, joint faculty development, and shared educational platforms, while the "Three Integrations" link research with education, theory with practice, and industry with teaching. Through these arrangements, university and industry partners participate more closely in the training process, helping to connect academic learning with engineering practice and better align student development with industry needs (Shah and Gillen, 2024; Vuoriainen et al., 2025).

3.3.1 Dual-teacher classroom teaching

In core courses such as Well Testing Analysis and Oil and Gas Reservoir Seepage Mechanics, teaching is jointly delivered by university faculty and experienced industry professionals. Engineering cases from PetroChina and Sinopec are incorporated into classroom discussion so that students can relate theoretical concepts more directly to field practice. This arrangement places greater emphasis on practical production problems rather than textbook knowledge alone. The model has so far been used for more than 400 teaching hours and has involved over 800 students.

3.3.2 Progressive industry training

The program collaborates with major state-owned energy companies, including PetroChina, Sinopec, and Chongqing Shale Gas Company, as well as selected private enterprises, to organize industry-based training. Rather than relying mainly on short observational internships, practical training is arranged progressively across different stages of study. Junior students complete at least 60 days of on-site training under industry supervision. Senior students undertake graduation projects with joint guidance from university and industry supervisors, with training lasting no less than 120 days. Graduate students involved in major research projects complete at least 200 days of field-based training. Hundreds of students participate in these activities each year (Jackson, 2015; Jackson and Dean, 2023; Hwang et al., 2026).

3.3.3 Competition-based practical training

Discipline competitions form an important part of the practical training system. To prepare students for these activities, the program has developed teaching case libraries and engineering training resources covering areas such as

technology development and project management, while competition-related tasks are incorporated into the practical curriculum. Over the past eight consecutive years, the teaching team has guided students in the China Petroleum Engineering Design Competition, one of the major national competitions in petroleum engineering education. During this period, students received eight national first prizes and one special prize. Related teaching practices were also recognized through a key teaching reform project in Sichuan Province and the First Prize of the Sichuan Provincial Teaching Achievement Award.

3.4 Innovation and entrepreneurship education

To improve the connection between research, innovation, and entrepreneurship education, the program makes use of the Natural Gas Modern Industry College, one of China's first modern industry colleges. The college provides a platform for bringing current research resources into student training and for supporting innovation-oriented activities. Building on this platform, the program has developed an "education-practice-incubation-entrepreneurship" pathway that connects academic learning, research participation, project incubation, and entrepreneurial development (Täks et al., 2014; Huang-Saad et al., 2018; Browning and Bustard, 2024).

3.4.1 Progressive innovation pathway

The program organizes innovation training as a progressive process that follows students' development from initial exploration to project incubation. Inquiry-based and exploratory teaching is introduced at an early stage to encourage interest in innovation. Students then take part in research case studies, open laboratory activities, and faculty- or industry-supported projects, where they gain experience in research and apply their knowledge to practical problems. At a later stage, the Modern Industry College provides opportunities for technology transfer and practical training, allowing projects with market potential to be further refined and incubated (Nabi et al., 2017; Browning and Bustard, 2024).

3.4.2 Research incubation and commercialization

Undergraduate and graduate students are introduced to research projects and laboratory work at an early stage of their training. Under faculty supervision, they may progress from supporting roles to more substantial responsibilities within project teams, including participation in key technical tasks. Building on several core patents, twelve master's and doctoral students, together with faculty members, established Chengdu Zhishui Gas Production Technology Co., Ltd. The company focuses on technologies and products for gas-field water invasion warning and control, addressing practical problems in gas reservoir development. Its annual revenue has exceeded RMB 2 million, with eight invention patents, thirteen utility model patents, and six software copyrights obtained to date.

3.4.3 Innovation and entrepreneurship competitions

Building on its research and industry experience, the faculty-student team has participated in a number of innovation and entrepreneurship competitions. The team received one gold award and two silver awards in the Sichuan International College Students' Innovation Competition. The project Intelligent Water Control: An Intelligent Water Invasion Prediction and Control Decision-Making System for Gas Reservoir Development, jointly developed by faculty and students, also received a national bronze award in the 2023 China International College Students' "Internet+" Innovation and Entrepreneurship Competition. Related work was further recognized through a Sichuan Provincial Key Education Reform Project and the Special Prize of the university-level Teaching Achievement Award.

4. Implementation outcomes and evidence

4.1 Talent development outcomes

With the continued implementation of the "Four-in-One" system, changes in student development have become increasingly visible. Ideological and political education, in particular, has placed greater emphasis on professional responsibility, commitment to the energy industry, and professional identity. Mao Zhenglin provides one example. During his studies, he received the title of "Chinese College Student Self-Improvement Star" from the Central Committee of the Communist Youth League. After graduation, he joined PetroChina and worked in western oilfields, including the Tarim region, where he has been involved in frontline energy development.

Broader outcomes can also be seen in students' engineering, innovation, and entrepreneurship performance. Graduates are generally reported to have a solid theoretical foundation, practical engineering experience, and increasing awareness of market and business needs. Students have also received awards in discipline-based and innovation and entrepreneurship competitions, while several student-led projects have moved beyond the laboratory stage toward commercialization and business operation.

4.2 Teaching reform outcomes

Curriculum development and teaching reform have progressed alongside changes to the talent development model. The Petroleum Engineering program was recognized as a provincial demonstration program for curriculum-based ideological and political education in Sichuan Province. The implementation of the system also contributed to several teaching reform outcomes, including the First Prize of the Sichuan Provincial Teaching Achievement Award and the Special Prize of the Southwest Petroleum University Teaching Achievement Award.

5. Summary of experience and key lessons

The experience gained from developing the "education-practice-incubation-entrepreneurship" system may be relevant to the reform of other professionally oriented programs in science, engineering, agriculture, and medicine, particularly where closer links between disciplinary learning, practice, and innovation are needed.

Values education remains an important part of the training process. In engineering programs, professional knowledge and technical skills can be taught alongside

professional ethics, social responsibility, and the traditions of the discipline. In petroleum engineering, for example, the history and professional culture of the energy industry provide materials that can be incorporated into course content rather than treated as a separate element. This allows students to develop professional competence while also gaining a clearer understanding of their responsibilities to industry and society.

Talent development also needs to remain responsive to changes in technology and industry. Trends such as digitalization, intelligent technologies, and the low-carbon transition are reshaping the knowledge and skills expected of engineering graduates. Curriculum structures and teaching content therefore need regular adjustment so that they remain relevant to current professional practice and broader national priorities, including China's "dual carbon" goals.

University-industry collaboration is particularly important for the practical dimension of engineering education. Long-term partnerships allow students to encounter real engineering environments and gain experience that cannot be fully reproduced in classroom settings. When universities contribute disciplinary and theoretical expertise and industry partners provide engineering cases, facilities, and field-based training, students are able to connect academic learning more directly with professional practice. Such arrangements can also ease the transition from university study to engineering work (Shah and Gillen, 2024; Vuoriainen et al., 2025; Hwang et al., 2026).

Innovation and entrepreneurship are more effective when they are embedded in professional education rather than treated as separate activities. Research projects, professional courses, practical training, and incubation platforms can be linked so that students have opportunities to develop ideas, test their technical feasibility, and explore possible applications. Policy, funding, mentoring, and facilities provide further support for moving suitable research outcomes toward commercialization or industrial use. In this way, the links among education, practice, incubation, and entrepreneurship become part of the training process itself rather than an additional activity outside the curriculum (Nabi et al., 2017; Huang-Saad et al., 2018; Browning and Bustard, 2024).

6. Conclusion

Petroleum engineering education is being reshaped by both changes in the energy industry and the continuing reform of higher education in China. As the sector moves toward lower-carbon, greener, and more intelligent development, conventional training models are becoming less suited to the broader knowledge and competency requirements now expected of graduates. Petroleum engineering programs therefore need training systems that are more responsive to technological change, industry needs, and the responsibilities associated with national energy security.

Against this background, the Petroleum Engineering program at Southwest Petroleum University has established an integrated "education-practice-incubation-entrepreneurship" talent development system. The framework brings together ideological and political education, curriculum reform, practical training, and innovation-oriented development. These components connect values education with professional learning, classroom knowledge with engineering practice, and research participation with incubation, entrepreneurship, and commercialization. Rather than treating these activities as separate parts of the curriculum, the system organizes them within a coordinated training process and provides an example of how petroleum engineering education can respond to changing professional demands.

Future development will continue to reflect China's "dual carbon" goals, national energy priorities, and the low-carbon, green, and intelligent transformation of the oil and gas industry. Further work will focus on closer university-industry collaboration, regular renewal of curriculum content, and broader international opportunities for innovation and entrepreneurship. Attention will also be given to preparing graduates with professional competence, social responsibility, an international perspective, and the capacity for innovation, so that talent development remains closely connected with the long-term needs of the energy sector.

Conflicts of interest

The author declares no competing interest.

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