Higher Engineering Education Transformation

Vol. 2, No. 1, p. 1-8, 2026

heet.yandypress.com

Original article

Developing interdisciplinary engineering competencies for oil, gas and new energy integration: A progressive practical teaching framework

Wentong Zhang [1,2], Qixin Jia [1], Yanwei Wang [2], Shiming Wei [2,*]

[1] *College of New Energy and Electrical Engineering, Xi'an Petroleum University, Xi'an 710065, P. R. China*
[2] *State Key Laboratory of Petroleum Resources and Engineering, China University of Petroleum, Beijing 102249, P. R. China*

Keywords:
Energy integration
engineering education
engineering competency
practical teaching
project-based learning

Cited as:
Zhang, W., Jia, Q., Wang, Y., Wei, S. Developing interdisciplinary engineering competencies for oil, gas and new energy integration: A progressive practical teaching framework. Higher Engineering Education Transformation, 2026, 2(1): 1-8.
https://doi.org/10.46690/heet.2026.04.01

Abstract: The low-carbon transition is driving closer integration between oil and gas development and new energy technologies, extending from renewable electricity supply to the coupling of energy inputs with production processes, subsurface energy utilization, and carbon management. These developments create interdisciplinary engineering problems that require students to connect knowledge across disciplinary boundaries and make decisions under integrated engineering constraints. However, conventional practical teaching is often organized around separate technical subjects, providing limited opportunities to develop such cross-domain connections. To address this gap, this study proposes a four-level progressive practical teaching framework for oil, gas and new energy integration: Fundamental understanding and data interpretation, Cross-domain scenario analysis, Integrated system design and decision-making, and open-ended innovation and inquiry. Learning tasks progress from interpreting multidisciplinary data to analyzing coupling relationships, evaluating technology applicability, designing and comparing integrated solutions, and investigating open-ended questions. Representative contexts include renewable electricity supply, electricity-assisted oil recovery, geothermal utilization, and carbon capture, utilization, and storage, with emerging electric-field and electrochemical processes incorporated as research-oriented extensions. Case- and project-based learning, physical experiments and simulation-based learning, university–industry collaboration and research integration, and competency-oriented assessment are incorporated as complementary implementation approaches. The framework provides a structured pathway for connecting new energy technologies with oil and gas engineering across energy supply, engineering processes, and subsurface systems.

1. Introduction

The transition toward lower-carbon energy systems is reshaping the relationship between oil and gas development and new energy technologies. Oil and gas operations remain closely associated with wells, reservoirs, production systems, and subsurface resources, while their energy supply and carbon-management requirements increasingly intersect with renewable electricity, energy storage, geothermal utilization, and carbon capture, utilization, and storage (CCUS). This integration is not limited to adding renewable generation to conventional production facilities. Renewable electricity can provide energy for surface operations and, through electrical or thermal processes, can also participate more directly in oil and gas development. Geothermal utilization and CCUS further connect surface energy or carbon-management objectives with wells and subsurface formations. These developments link energy supply, production processes, and subsurface engineering (Pinto Jr. et al., 2026).

These changes create corresponding challenges for engineering education. Knowledge relevant to integrated energy problems is commonly distributed across different courses and disciplinary domains. Students may learn renewable electricity generation, energy storage, reservoir and well engineering, geothermal utilization, or carbon management separately, but solving an integrated engineering problem requires them to establish relationships among these areas. Previous studies in energy-related engineering education have identified the importance of interdisciplinary learning, engineering practice, and stronger connections between technical knowledge and engineering applications (Van den Beemt et al., 2020; Wang and Guo, 2021; Peng, 2022; Babadagli, 2023; Liu et al., 2026; Pinto Jr. et al., 2026). Students must therefore learn to identify connections between energy technologies and oil and gas

*Corresponding author.
E-mail address: we_shiming@163.com
Received: July 30, 2026; revised: September 2, 2026; accepted: September 21, 2026; published: September 25, 2026.
ISSN: 3136-5221 © The Author(s) 2026.
Publisher's Note: Yandy stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Yandy Scientific Press

operations, assess their suitability under specific conditions, and justify engineering decisions.

Practical learning provides an important setting for developing these cross-domain connections. Recent technical studies have documented different pathways for integrating renewable energy technologies with oil and gas engineering, including the electrification of production operations, renewable electricity supply, and the reuse of existing subsurface infrastructure for low-carbon energy applications (Mohammadi et al., 2025; Motta et al., 2026). For example, designing a renewable electricity supply system for oil and gas operations requires students to relate photovoltaic or wind-power generation to production loads, grid conditions, and energy-storage requirements. Electricity-assisted heavy-oil recovery introduces a different form of integration in which electrical energy participates more directly in the production process, although its applicability depends on reservoir conditions, energy requirements, and technical and economic constraints (Bera and Babadagli, 2015). Geothermal utilization connects subsurface resource and well conditions with surface heat demand, including opportunities and limitations associated with repurposing existing oil and gas wells (Davoodi et al., 2024). CCUS requires consideration of CO_2 sources, transport, injection, storage suitability, and operational constraints (Baskaran et al., 2024). Emerging electric-field and electrochemical approaches provide additional research-oriented contexts for examining electrically induced fluid transport and interfacial responses, but their mechanisms and engineering applicability remain subject to further investigation (Zhang et al., 2025a; Zhang. et al., 2025b). Collectively, these scenarios represent different levels of technological maturity and provide complementary contexts for multidisciplinary data interpretation, technology applicability assessment, integrated engineering design, and evidence-based inquiry (Beck and Gale, 2009; Zarrouk, 2017).

To address these educational needs, this study proposes a four-level progressive practical teaching framework for oil, gas and new energy integration: Fundamental understanding and data interpretation, Cross-domain scenario analysis, Integrated system design and decision-making, and open-ended innovation and inquiry. The framework organizes learning according to increasing task complexity, disciplinary integration, and student autonomy, while connecting outputs across successive levels. Case- and project-based learning, physical experiments and simulation, university-industry collaboration and research integration, and competency-oriented assessment are incorporated as complementary implementation approaches. The framework is intended to provide a structured pathway for developing interdisciplinary engineering competencies across energy supply, engineering processes, and subsurface systems, progressing from the understanding of individual parameters and processes to integrated scenario analysis, engineering decision-making, and open-ended inquiry.

2. Educational needs and challenges for oil, gas and new energy integration

2.1 Emerging competency needs for oil, gas and new energy integration

Oil, gas and new energy integration increasingly involves interactions among renewable electricity, production systems, wells, reservoirs, subsurface resources, and carbon-management processes. Renewable electricity can supply oil and gas operations, while electrical energy can also participate more directly in production processes, such as electrically assisted thermal recovery. Geothermal utilization and CCUS further connect surface energy or carbon-management objectives with subsurface engineering. Electric-field and electrochemical research also introduces questions concerning fluid transport, multiphase interfaces, and CO_2–oil–rock interactions.

These forms of integration require students to move beyond understanding individual technologies toward connecting knowledge across disciplinary boundaries. Students need to interpret multidisciplinary data, identify relationships among energy inputs and engineering responses, assess technology applicability, and compare alternatives under technical, operational, economic, environmental, and energy constraints. Practical teaching should therefore progress from understanding parameters and processes to analyzing integrated scenarios, making and justifying engineering decisions, and investigating open-ended problems.

2.2 Key challenges in practical teaching

2.2.1 Bridging disciplinary knowledge across oil, gas and new energy

Knowledge relevant to oil, gas and new energy integration remains distributed across traditionally separate disciplinary domains. Renewable electricity involves generation, variability, storage, and energy management, whereas oil and gas development involves wells, reservoirs, production systems, and multiphase fluids; geothermal utilization, CCUS, and electricity-assisted subsurface processes introduce further cross-domain knowledge. Learning these topics independently does not ensure that students can establish the connections required by integrated engineering problems. The teaching challenge is therefore to create shared engineering contexts in which students identify how knowledge, parameters, and mechanisms from different domains are connected (Van den Beemt et al., 2020; Liu et al., 2026).

2.2.2 Connecting technical knowledge with integrated engineering scenarios

Interdisciplinary knowledge becomes meaningful only when students can determine how it applies to specific engineering scenarios. Different forms of oil, gas and new energy integration involve different coupling pathways. For renewable electricity supply, students need to relate generation profiles to oil and gas production loads, grid conditions, and storage requirements. In electricity-assisted heavy-oil recovery, they need to consider how electrical energy is delivered to the production process and how energy input relates to operating conditions and production requirements. Geothermal utilization requires matching subsurface resource conditions with surface energy demand, while CCUS requires consideration of CO_2 sources, transport, injection, storage suitability, and operational constraints.

The challenge is therefore not simply to expose students to multiple technologies, but to enable them to determine how and under what conditions these technologies interact with oil, gas, or subsurface engineering

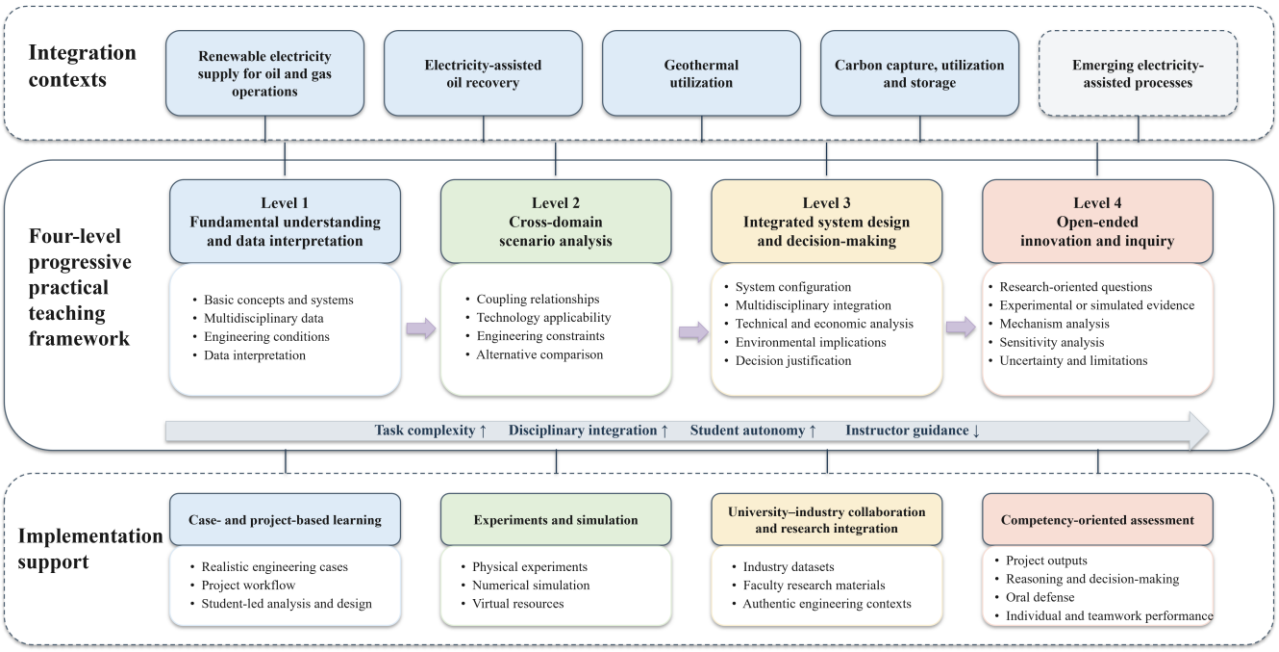


Figure 1 Progressive practical teaching framework for oil, gas and new energy integration

processes. This is particularly important for emerging electricity-assisted processes, where experimental observations should not automatically be interpreted as evidence of field-scale feasibility. Teaching cases should therefore retain the resource, operating, subsurface, and energy constraints that influence engineering judgment while distinguishing established applications from research-oriented possibilities.

2.2.3 Designing integrated and open-ended engineering tasks

Engineering problems involving oil, gas and new energy integration contain multiple interacting variables and different levels of technological maturity. A renewable electricity supply problem may involve generation–load matching, storage, reliability, economics, and carbon emissions, whereas electricity-assisted heavy-oil recovery additionally involves energy delivery, thermal response, and production conditions. Geothermal and CCUS problems introduce subsurface resource, injection, and storage constraints, while emerging electric-field or electrochemical processes involve additional uncertainties in translating experimental observations toward engineering conditions.

Practical tasks should retain the main engineering constraints while remaining manageable within the available teaching time and resources. Students should have sufficient information to compare alternatives without following a prescribed solution. Teaching tasks should therefore retain the variables and constraints that materially affect engineering decisions while simplifying secondary processes. Established applications can support scenario analysis and preliminary design, whereas emerging research topics are better formulated as open-ended inquiries based on experimental or simulated evidence, sensitivity analysis, and recognition of uncertainty (Mills and Treagust, 2003; Smith et al., 2005; Prince and Felder, 2006; Chen et al., 2021; Jin, 2026).

2.2.4 Assessing interdisciplinary engineering competencies

Assessment of integrated engineering tasks must capture not only final solutions but also how students connect disciplinary knowledge, interpret constraints, compare alternatives, and justify decisions under uncertainty. Project outcomes should therefore be combined with evidence from problem definition, parameter selection, data interpretation, calculations, design comparisons, assumptions, and individual contributions (Van den Beemt et al., 2020; Chan and Lee, 2021; Beddoes and Bartlett, 2026).

Assessment criteria should reflect the nature of the task. Engineering design activities are evaluated against technical requirements, while research-oriented activities are assessed through problem formulation, methodological choices, and interpretation of evidence.

3. Design of the progressive practical teaching framework

3.1 Overall framework

The proposed framework comprises four progressive levels: Fundamental understanding and data interpretation, Cross-domain scenario analysis, Integrated system design and decision-making, and open-ended innovation and inquiry. As shown in Fig. 1, the levels are organized by increasing task complexity, interdisciplinary integration, and student autonomy (Prince and Felder, 2006; Chen et al., 2021).

Representative engineering contexts were selected to reflect different coupling pathways between new energy technologies and oil and gas engineering, as well as differences in technological maturity and instructional suitability. Renewable electricity supply represents energy-system integration through photovoltaic, wind-power, and energy-storage systems, while electrically assisted thermal recovery illustrates the direct involvement of electrical energy in oil and gas production processes. Geothermal utilization and CCUS connect surface energy and carbon-management objectives with wells and subsurface formations. Emerging

electric-field and electrochemical approaches extend these contexts toward research-oriented questions involving fluid transport, interfacial interactions, and CO_2–oil–rock processes. Accordingly, these scenarios provide complementary opportunities for engineering analysis, preliminary system design, and open-ended inquiry, rather than representing technologies at an equivalent level of maturity.

Instructor guidance is gradually reduced as students assume greater responsibility for analysis, decision-making, and problem formulation. Table 1 summarizes the learning content, representative tasks, and competency focus of the four levels.

A renewable electricity supply system for an oil and gas production facility illustrates the progression across the four levels. At the Fundamental level, students analyze electricity demand and photovoltaic generation data. At the Scenario level, they evaluate supply–demand matching and operational constraints. At the design level, they develop and compare photovoltaic–battery configurations based on reliability, cost, and emission reduction. At the Innovation level, they examine operating uncertainties through sensitivity analysis and refine their designs. Each stage builds on the preceding results, connecting data interpretation, engineering assessment, system design, and open-ended inquiry within a single project.

3.2 Fundamental understanding and data interpretation

Fundamental understanding and data interpretation provides the technical basis for subsequent cross-domain learning. Students identify key parameters, interpret experimental or calculated results, and process data relevant to oil, gas and new energy integration, with emphasis on understanding what the results represent and under what conditions they can support engineering analysis.

Activities can cover both surface energy systems and subsurface processes. Students may analyze photovoltaic or wind-power output and energy-storage behavior; interpret electrical power, energy consumption, and temperature responses in electricity-assisted processes; estimate geothermal resources from formation and fluid parameters; or examine key parameters associated with CO_2 transport, injection, and geological storage. Research-derived datasets may also be used to examine relationships between electrical conditions and measured fluid, interfacial, or transport responses, without requiring students to infer field-scale effectiveness from laboratory observations.

Students summarize the key parameters, explain their data-processing methods, and identify the conditions under which the results can be used in subsequent engineering analysis.

3.3 Cross-domain scenario analysis

Cross-domain scenario analysis connects technical knowledge with the needs and constraints of integrated engineering scenarios. Students identify engineering objectives, resource conditions, process requirements, and limiting factors and assess how, why, and under what conditions different integration pathways are applicable.

Representative cases include matching photovoltaic or wind-power generation with oilfield production loads and storage requirements; examining energy delivery, thermal response, and operational constraints in electricity-assisted heavy-oil recovery; relating geothermal resource conditions to surface heat demand; and evaluating CO_2 sources, transport, injection, and storage conditions in CCUS. Research-oriented scenarios can further use experimental or simulated evidence to examine electric-field effects on fluid transport, phase behavior, interfacial interactions, or CO_2–oil–rock systems. In such cases, students distinguish experimentally supported observations from conclusions about engineering applicability.

Students summarize the relevant data, engineering constraints, and feasible technology options. Their scenario assessment establishes the requirements for the subsequent design stage.

3.4 Integrated system design and decision-making

Integrated system design and decision-making extends scenario analysis from technology applicability to system configuration, parameter selection, alternative comparison, and engineering justification. Students work with defined requirements and constraints but without a prescribed technical route, and develop preliminary designs appropriate to available teaching time, data, facilities, and prior knowledge.

A representative task is the preliminary design of a renewable electricity supply system for oil and gas operations. Using production loads, solar and wind resources, grid conditions, equipment parameters, and energy prices, students select combinations of renewable generation and storage, estimate capacity requirements, develop operating strategies, and compare alternatives in terms of energy performance, reliability, economics, and carbon reduction. Assumptions, parameter sources, system boundaries, and limitations should be stated explicitly.

Design tasks can also address the more direct coupling of electrical energy with oil and gas development. In electricity-assisted heavy-oil recovery, for example, students may consider electricity supply, power demand, energy delivery, thermal requirements, and production constraints and compare alternative configurations in terms of energy consumption and operational performance. Geothermal and CCUS projects can similarly require students to match subsurface conditions with utilization, injection, or storage requirements. Emerging electric-field or electrochemical concepts are more appropriately examined through comparative or sensitivity analysis than treated as established design options.

Designs are evaluated according to their technical feasibility, treatment of engineering constraints, calculation accuracy, and justification of the selected configuration.

3.5 Open-ended innovation and inquiry

Open-ended innovation and inquiry extend unresolved questions and uncertainties from preceding levels into manageable problems for further investigation. Students take greater responsibility for defining problems, selecting methods, interpreting evidence, and evaluating limitations. Inquiry tasks are selected according to the available questions, data, and teaching resources (Noguez and Neri, 2019).

Topics can originate from preceding activities, faculty research, emerging engineering practices, or adapted industry problems. Research-oriented topics may extend to the interface between electrical energy and subsurface processes. Students may investigate electric-field effects on

Table 1 Four-level progressive practical teaching framework

Level	Learning focus	Representative tasks	Competency focus
Fundamental understanding and data interpretation	Principles; key parameters; data interpretation	Renewable electricity and storage data; electrical/thermal response; geothermal and CCUS parameters	Technical understanding; data interpretation
Cross-domain scenario analysis	Engineering needs; coupling relationships; technology applicability	Renewable electricity supply; electricity-assisted heavy-oil recovery; geothermal and CCUS scenarios	Knowledge connection; scenario analysis; applicability assessment
Integrated system design and decision-making	System configuration; parameter selection; alternative comparison	Wind/photovoltaic–storage design; electricity-assisted recovery configuration; geothermal or CCUS design	System integration; engineering design; decision-making
Open-ended innovation and inquiry	Problem formulation; evidence analysis; uncertainty	Electric-field-assisted oil recovery and CO_2 processes; sensitivity analysis; research/industry problems	Open-ended inquiry; evidence-based reasoning; critical evaluation

fluid transport and phase behavior, oil–water–rock interactions, electrically assisted CO_2-oil displacement, or the potential role of electrical regulation in CO_2 utilization and geological storage. Other topics may involve geothermal reinjection, CO_2 injection and storage, or integrated energy-system operation. For emerging electric-field and electrochemical approaches, students examine proposed mechanisms, interpret experimental or numerical results, and assess the conditions under which these findings may be relevant to engineering applications.

Depending on the question, students may analyze literature or research-derived datasets, compare mechanisms or model assumptions, conduct sensitivity or numerical analyses, or undertake limited experiments. Faculty research data can be adapted to examine relationships among electrical input, fluid or interfacial responses, and engineering conditions without requiring reproduction of a complete research study.

Instructors help students define research questions, select appropriate methods, and interpret their findings. Unexpected or inconclusive results remain valuable when supported by a sound investigation and clear documentation. Suitable topics may be extended into undergraduate innovation projects or graduation projects.

4. Implementation of the progressive practical teaching framework

4.1 Case- and project-based learning

Case- and project-based learning organizes the module around engineering problems (Mills and Treagust, 2003; Smith et al., 2005; Prince and Felder, 2006; Chen et al., 2021; Jin, 2026). Students work in groups to identify constraints, select technical options, complete preliminary designs, compare alternatives, and present their findings. Instructors provide datasets, technical guidance, and feedback at key stages.

For the renewable electricity supply project, the instructor provides an adapted facility load profile, renewable generation data, equipment specifications, and energy-price information. Student groups first calculate electricity demand and identify operating constraints, then develop two or more photovoltaic–battery configurations using spreadsheet-based calculations. They compare the configurations in terms of supply reliability, cost, and potential emission reductions, and submit a design report documenting their assumptions, calculations, and recommended solution. Following group presentations, the instructor provides feedback on parameter selection, engineering feasibility, and the justification of design decisions.

The workflow can also be adapted to electricity-assisted oil recovery, geothermal utilization, and CCUS, with research-oriented topics used for open-ended inquiry.

4.2 Target students and module configuration

The proposed framework is intended for third- and fourth-year undergraduate students majoring in new energy science and engineering and is organized as an integrated practical teaching module on oil, gas and new energy integration. Students are expected to have basic knowledge of renewable energy generation, energy storage, and engineering data analysis. Since their prior exposure to petroleum engineering may be limited, introductory materials on oil and gas production systems, well operations, and subsurface engineering are provided before the corresponding practical activities.

A 32-hour module is proposed, comprising four progressive learning stages. Fundamental understanding and data interpretation is allocated 6 hours, focusing on engineering parameters, energy data, and basic calculations. Cross-domain scenario analysis is allocated 8 hours to examine relationships between energy supply, production requirements, and engineering constraints. Integrated system design and decision-making is allocated 12 hours for system configuration, quantitative comparison, and engineering justification. Open-ended innovation and inquiry is allocated 6 hours for sensitivity analysis, exploration of alternative operating conditions, and presentation of findings. The module adopts group-based project learning, supported by instructor briefings, structured datasets, engineering calculations, and guided discussions. Students work in groups of four to five, with responsibilities for data processing, engineering analysis, design comparison, and reporting distributed among group members. Each stage produces a defined output that serves as an input to the subsequent stage. A renewable electricity supply system for an oil and gas production facility is used as the principal teaching case, while geothermal utilization, CCUS, and electricity-assisted recovery provide supplementary contexts. The proposed module can be implemented using documented engineering

Table 2 Proposed assessment categories, weights, and evidence for practical learning

Assessment category	Proposed weight	Main assessment evidence and criteria
Fundamental understanding and data interpretation	20%	Experimental/data records; parameter interpretation; data processing and limitations
Cross-domain scenario analysis	20%	Engineering needs and constraints; cross-domain connections; technology applicability and justification
Integrated system design and decision-making	30%	Parameter selection and calculations; constraint satisfaction; alternative comparison; design justification
Presentation and oral defense	15%	Report and system diagram; responses to questions; explanation of assumptions, decisions, and limitations
Open-ended inquiry and teamwork	15%	Problem exploration; evidence interpretation; revision records; individual contribution and collaboration

datasets and commonly available computational tools, without requiring access to operating oilfields or specialized subsurface experimental facilities. Learning outcomes are assessed through staged assignments, group design reports, individual contributions, and oral presentations, following the competency-oriented assessment criteria presented in Table 2.

4.3 Integration of physical experiments and simulation-based learning

Physical experiments, numerical simulation, and virtual resources provide complementary forms of practical learning. Direct measurements can support the study of renewable electricity generation, energy-storage behavior, and selected electrical or thermal responses, whereas processes such as geothermal flow and heat transfer or geological CO_2 storage may require appropriately simplified models (Balamuralithara and Woods, 2009; Potkonjak et al., 2016; Hu et al., 2021; Li and Liang, 2024; Ma et al., 2025).

The emphasis is placed on matching the method to the engineering question rather than on software operation itself. Tools such as COMSOL Multiphysics and MATLAB can support simulation and data analysis, while research-derived datasets can provide additional evidence for interpreting electricity-assisted fluid, interfacial, or transport responses. Students are expected to relate results to parameter sources, assumptions, and boundary conditions and, where possible, compare them with experimental or reference data.

Virtual field resources, including equipment layouts, process diagrams, and site videos, can provide additional engineering context. Experiments, simulation, and visualization therefore serve complementary purposes and should be selected according to the learning task (Balamuralithara and Woods, 2009; Potkonjak et al., 2016; Li and Liang, 2024; Wang and Liu, 2024).

4.4 University–industry collaboration and research integration

University–industry collaboration and research integration provide authentic materials for implementing the framework. Where available, authorized and de-identified industry data can introduce production requirements, resource conditions, and operational constraints, while faculty research can contribute experimental or simulation datasets, analytical methods, and unresolved questions adapted to the intended learning level (Noguez and Neri, 2019).

These sources serve complementary purposes. Industry materials are particularly suitable for scenario analysis and preliminary design, whereas research materials can support data interpretation and open-ended inquiry. Operational cases involving renewable electricity supply or electricity-assisted oil recovery can provide engineering contexts, while research data on electric-field effects on fluids, interfaces, or CO_2–oil–rock processes can support the analysis of mechanisms, evidence, and uncertainty.

4.5 Competency-oriented assessment

Competency-oriented assessment combines project outcomes with evidence of students' reasoning and decision-making processes (Jin, 2026; Chan and Lee, 2021; Beddoes and Bartlett, 2026). Needs analyses, parameter tables, calculation files, design reports, and comparison records can be used to examine how students interpret engineering conditions, connect multidisciplinary knowledge, compare alternatives, and justify decisions. Oral defense and individual contribution records provide complementary evidence of individual understanding in group projects.

Assessment criteria are aligned with the four-level progression. Fundamental activities emphasize data interpretation; scenario analysis emphasizes cross-domain connections and technology applicability; integrated design emphasizes system-level reasoning and decision justification; and open-ended inquiry emphasizes problem formulation, evidence interpretation, and recognition of uncertainty. For research-oriented activities, unexpected or inconclusive results can remain meaningful when the investigation is appropriately designed and interpreted.

Table 2 summarizes the proposed assessment categories, weights, and corresponding evidence. Integrated design receives the largest weight because it synthesizes data interpretation, scenario analysis, and engineering decision-making, while presentation and oral defense provide cross-cutting evidence of individual understanding.

5. Conditions for implementation and continuous improvement

Implementation involves three components: teaching resources, interdisciplinary instructor coordination, and

feedback based on student learning outcomes.

5.1 Practical learning resources

Implementation can build on existing laboratory facilities while incorporating engineering datasets, research-derived data, simulation tools, and virtual resources according to the selected tasks. Project briefs, parameter datasets, and reference materials should be coordinated across successive levels so that outputs from earlier activities can support later scenario analysis and design.

Resource preparation should also reflect the maturity of the selected topic. Established engineering cases can use adapted operational data and design parameters, whereas emerging electricity-assisted or other research-oriented topics can use experimental datasets, numerical results, or literature evidence for analysis and inquiry. Core activities should remain feasible with available facilities and software so that specialized equipment or external data access does not become a prerequisite for completing the course.

5.2 Interdisciplinary teaching team

The framework requires coordinated guidance across energy, oil and gas, and subsurface engineering domains. Instructors with backgrounds in renewable energy can support electricity generation, storage, and energy-system analysis, while those with expertise in reservoirs, wells, production, geothermal systems, or CCUS can provide guidance on subsurface conditions and engineering processes. Topics involving electricity-assisted subsurface processes may additionally draw on expertise in electrical, interfacial, or electrochemical phenomena where appropriate.

Joint preparation is needed to define knowledge connections, task boundaries, datasets, and assessment expectations. A course coordinator can maintain consistency across successive learning levels, while instructtors with relevant expertise provide guidance for specific tasks.

5.3 Feedback and continuous improvement

Continuous improvement should be based on identifiable difficulties in student learning rather than on general impressions of teaching effectiveness. Repeated errors in parameter interpretation or data processing may indicate insufficient foundational preparation; technically correct calculations without adequate justification of technology selection may indicate weaknesses in scenario analysis; and highly similar designs across groups may suggest insufficient scope for independent decision-making. Difficulties in defining questions or interpreting inconclusive evidence can similarly indicate the need for additional guidance in open-ended inquiry.

After each implementation cycle, the teaching team can review staged assignments, design outputs, oral-defense records, and student revisions to identify where tasks, datasets, guidance, or assessment criteria require adjustment. Interpretation of these records should consider differences in student preparation and task difficulty. The findings can guide adjustments to teaching materials, task difficulty, instructor support, and assessment criteria.

6. Conclusions

This paper proposes a four-level progressive practical teaching framework for developing interdisciplinary engineering competencies in oil, gas and new energy integration. The framework organizes practical learning from fundamental understanding and data interpretation to cross-domain scenario analysis, integrated system design and decision-making, and open-ended inquiry. By connecting learning tasks across energy supply, engineering processes, and subsurface systems, it extends oil, gas and new energy integration beyond the external supply of renewable energy toward more direct interactions between energy inputs and engineering processes, while distinguishing established engineering applications from emerging research-oriented approaches.

The proposed framework represents a teaching design rather than evidence of demonstrated learning gains. Its effectiveness should therefore be evaluated through future implementation under specific course conditions, taking into account student preparation, teaching time, available resources, and task difficulty. Evidence from staged assignments, design outputs, oral defense, and open-ended inquiry can be used to examine the coherence of the four levels, the appropriateness of task progression, and the alignment between learning activities and competency-oriented assessment. Such evidence can then support iterative refinement of the framework without assuming educational effectiveness in advance.

Conflicts of interest

The authors declare no competing interests.

Open Access

This article is distributed under the terms and conditions of the Creative Commons Attribution (CC BY-NC-ND) license, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Acknowledgments

The authors acknowledge the support of the Undergraduate Education and Teaching Reform Project of China University of Petroleum (Beijing), under the project entitled “Strengthening Foundations, Empowering, and Fostering Innovation: Teaching Reform and Practice in University Physics”.

References

Babadagli, T. Reassessment of petroleum engineering education: Is it the end of an era or a new start? Education for Chemical Engineers, 2023, 43: 1–9.

Balamuralithara, B., Woods, P. C. Virtual laboratories in engineering education: The simulation lab and remote lab. Computer Applications in Engineering Education, 2009, 17(1): 108–118.

Baskaran, D., Saravanan, P., Nagarajan, L., et al. An overview of technologies for capturing, storing, and utilizing carbon dioxide: Technology readiness, large-scale demonstration, and cost. Chemical Engineering Journal, 2024, 491: 151998.

Beck, B., Gale, J. Improving the global carbon capture and

storage educational capacity. Energy Procedia, 2009, 1(1): 4727–4733.

Beddoes, K., Bartlett, K. Assessing interdisciplinary learning and knowledge: A state-of-the-art review and heuristic. Journal of Engineering Education, 2026, 115(2): e70062.

Bera, A., Babadagli, T. Status of electromagnetic heating for enhanced heavy oil/bitumen recovery and future prospects: A review. Applied Energy, 2015, 151: 206–226.

Chan, C. K. Y., Lee, K. K. W. Constructive alignment between holistic competency development and assessment in Hong Kong engineering education. Journal of Engineering Education, 2021, 110(2): 437–457.

Chen, J., Kolmos, A., Du, X. Forms of implementation and challenges of PBL in engineering education: A review of literature. European Journal of Engineering Education, 2021, 46(1): 90–115.

Davoodi, S., Al-Shargabi, M., Wood, D. A., et al. Geothermal energy recovery from abandoned petroleum wells: A review of the challenges and opportunities. Sustainable Energy Technologies and Assessments, 2024, 68: 103870.

Hu, M., Ji, J., Duan, J., et al. Distributed wind power virtual simulation experiment system for cultivating the ability to solve complex engineering problems. Computer Applications in Engineering Education, 2021, 29(6): 1441–1452.

Jin, J. Evidence-governed artificial intelligence learning in Applied Optics. Higher Engineering Education Transformation, 2026, 1(2): 24–32.

Li, J., Liang, W. Effectiveness of virtual laboratory in engineering education: A meta-analysis. PLOS One, 2024, 19(12): e0316269.

Liu, L., Zhang, A., Xu, G., et al. Teaching reform of hydrogeology and engineering geology for environmental engineering undergraduates under the emerging engineering education initiative. Higher Engineering Education Transformation, 2026, 1(2): 19–23.

Ma, L., Xiong, J., Wang, X., et al. Development of a Unity3D-based virtual simulation tool for hydrogen fuel cell performance testing in engineering education. Computer Applications in Engineering Education, 2025, 33(6): e70095.

Mills, J. E., Treagust, D. F. Engineering education – Is problem-based or project-based learning the answer? Australasian Journal of Engineering Education, 2003, 1–16. https://hdl.handle.net/1959.8/42023

Mohammadi, S., Berg, C. F., Schümann, H. Low-emission offshore oil and gas production: A review of achievements and challenges. Journal of Cleaner Production, 2025, 525: 146504.

Motta, I. L., Zobisch Jr., E. W., Vieira Jr., G. L., et al. Energy transition in the oil and gas sector: Decarbonization strategies and repurposing infrastructure for a net-zero future. Annual Review of Environment and Resources, 2026, 51: 305–333.

Noguez, J., Neri, L. Research-based learning: A case study for engineering students. International Journal on Interactive Design and Manufacturing, 2019, 13: 1283–1295.

Peng, J. Exploration on curriculum system reform of new energy science and engineering specialty under the background of emerging engineering education. Journal of Tianjin Agricultural University, 2022, 29(2): 88–91. (in Chinese).

Pinto Jr., H. Q., Oroski, F., Alves, F., et al. Engineering education for the energy transition: Shaping up new human resources. Annual Review of Environment and Resources, 2026, 51: 335–356.

Potkonjak, V., Gardner, M., Callaghan, V., et al. Virtual laboratories for education in science, technology, and engineering: A review. Computers & Education, 2016, 95: 309–327.

Prince, M. J., Felder, R. M. Inductive teaching and learning methods: Definitions, comparisons, and research bases. Journal of Engineering Education, 2006, 95(2): 123–138.

Smith, K. A., Sheppard, S. D., Johnson, D. W., et al. Pedagogies of engagement: Classroom-based practices. Journal of Engineering Education, 2005, 94(1): 87–101.

Van den Beemt, A., MacLeod, M., Van der Veen, J., et al. Interdisciplinary engineering education: A review of vision, teaching, and support. Journal of Engineering Education, 2020, 109(3): 508–555.

Wang, X., Guo, L. How to promote university students to innovative use renewable energy? An inquiry-based learning course model. Sustainability, 2021, 13(3): 1418.

Wang, Y., Liu, Y. Construction of a virtual simulation practical teaching system for intelligent manufacturing under the background of new engineering. Computer Applications in Engineering Education, 2024, 32(5): e22768.

Zarrouk, S. J. Postgraduate geothermal energy education worldwide and the New Zealand experience. Geothermics, 2017, 70: 173–180.

Zhang, D., Liu, Q., Zhou, X., et al. A review of electrically enhanced oil recovery (EEOR): Mechanism, influencing factors and field application effects. ACS Omega, 2025a, 10(50): 61096–61123.

Zhang, W., La, J., Tan, H., et al. Electric-field assisted enhancement of CO_2/hydrocarbon miscibility for tight sandstone oil recovery: Experimental and molecular dynamics insights. Colloids and Surfaces A: Physicochemical and Engineering Aspects, 2025b, 727: 138399.