ISSN 2522-6398 Vol. 8, Issue 10: 29-34, DOI: 10.25236/FER.2025.081005

Case-Based Teaching to Drive Engineering Competency Development: Innovation and Practice in Refractory Materials Course Instruction

Zhao Ping[1,a,*], Lou Youxin[1,b,*], Zhou Haifeng[1,c], Hao Meilun[1,d], Yang Zi[2,e], Li Qin[1,f], Xu Yue[1,g], Qiao Congde[1,h]

[1]School of Materials Science and Engineering, Qilu University of Technology (Shandong Academy of Sciences), Jinan, China
[2]Henan Building Materials Research and Design Institute Co., Ltd, Zhengzhou, China
[a]zhaoping6101@qlu.edu.cn, [b]zylyx616866@163.com, [c]hfzhou@qlu.edu.cn, [d]haoml@qlu.edu.cn, [e]yzdlc@hotmail.com, [f]liqin@qlu.edu.cn, [g]woxuyue@126.com, [h]cdqiao@126.com
[*]Corresponding author

Abstract: *This work proposes a novel teaching model that aims to address the challenges encountered in the education of engineering competencies. The challenges in focus pertain to the abstract nature of traditional refractory materials course content and the disconnection between theory and practice. The proposed teaching model of case-driven and three-dimensional interactive nature is proposed. The Inorganic Nonmetallic Materials Engineering programme has undergone a series of systematic teaching reforms. These reforms have been implemented by integrating a real-world engineering cases, employing blended teaching methods, and emphasizing engineering competency enhancement. The practical outcomes demonstrate that this model effectively enhances students' engineering problem-solving abilities, strengthens their understanding of theoretical knowledge, and improves their capacity to analyse complex operational conditions. This approach provides a new pathways for curriculum reform in engineering education.*

Keywords: *Case-Based Teaching, Refractory Materials, Engineering Competency, Teaching Model*

1. Introduction

As a specialized course in inorganic non-metallic materials engineering, refractories encompass a complex body of knowledge that includes material composition, structural properties and production processes. The subject exhibits the characteristics of 'three abundances and three difficulties: an abundance of concepts, process parameters and failure mechanisms, which collectively create learning challenges for students, such as difficulties in comprehension, knowledge connections and practical applications [1]. The traditional linear teaching model, centred on instructor-led lectures and knowledge retention, struggles to develop students' engineering decision-making skills for real-world applications such as metallurgical high-temperature vessels and hot blast stoves. Accreditation of contemporary engineering education emphasizes cultivating 'the ability to solve complex engineering problems', thereby creating an urgent need to innovate teaching models for courses. Such problems are not merely intricate technical puzzles that can be solved by a single technology or discipline [2]. Instead, they require the integration of knowledge, innovative thinking and collaborative decision-making skills[3]. Therefore, fostering this capability depends on possessing a broad knowledge base, innovative thinking, a pioneering spirit and research capabilities.

2. Model Construction: Case-Driven and Three-Dimensional Interactive Framework Design

This model uses a repository of real-world engineering cases and incorporates blended learning methodologies to improve students' core competencies in solving complex engineering problems. By combining case analysis with practical blended exercises, it strengthens students' theoretical knowledge and their ability to analyse complex operational scenarios, integrating knowledge, skills and competencies.

ISSN 2522-6398 Vol. 8, Issue 10: 29-34, DOI: 10.25236/FER.2025.081005

2.1 Instructional Content: Knowledge Reconstruction Driven by Engineering Case Repositories

The objective facts encountered in engineering practice are summarized and organized using various media, such as text, data, charts and animations, to create case studies. These case studies are then discussed or explored in the classroom, enabling abstract theoretical knowledge to be made more specific and contextual. This approach addresses the challenge of 'abstract content' that students often encounter during their studies. Integrating cases throughout the course facilitates the interconnection of disparate knowledge points into a cohesive network, diverging from conventional teaching methodologies and content structures. Consequently, teaching content must be restructured to align with this new instructional model. The present study proposes modularized knowledge by dividing course content into relatively independent 'modules'. Each module focuses on specific competencies or knowledge points based on the course objectives.

(1) Production Process Module: In the study of refractory materials, mastering production processes is critical, as they are the link between material design and engineering applications. Production processes are fundamental to understanding how material performance is realized and are the primary driver of technological innovation. They also constitute the core element of product quality control. For researchers, new process technologies are the key to the commercialization of laboratory innovations, while for engineers, process knowledge is vital for troubleshooting and cost optimization. For students, understanding processes is the vital link in the knowledge chain of “composition-structure-property-application”. A student's ability to solve complex engineering problems depends on a solid foundation of professional knowledge, an innovative product resulting from the integration and refinement of diverse information. Consequently, establishing a robust professional foundation is fundamental to promoting innovation. The core objectives of this module are as follows: To comprehend how diverse categories of refractory materials are produced, it is crucial to understand how the manufacturing process influences their final structure and properties. Main content includes: The fundamentals of raw materials, batching and mixing, forming processes, drying, firing, post-treatment and machining, quality inspection and control, and related topics.

(2) Fundamental Properties Module: Mastery of these properties is crucial for conducting material design, selecting suitable applications and predicting service behaviour. This process requires a thorough grasp of the underlying technical principles and application logic. Performance parameters serve two functions: firstly, they provide quantitative criteria for evaluating material suitability; secondly, they establish a critical link between theoretical research and industrial practice. For engineers, performance parameters are essential for making decisions relating to material selection, acceptance testing, and failure analysis. For developers, performance targets guide material design and provide a benchmark for iterative evaluation. For students, understanding performance parameters provides the cognitive basis for grasping high-temperature materials science. This module has three fundamental objectives: firstly, to master the KPIs used to evaluate the quality of refractory materials; secondly, to understand the testing methods used to assess these materials; and thirdly, to comprehend the physical significance of the KPIs and their relationship to performance, composition, structure and processing. The essential content comprises physical properties, high-temperature service performance, chemical and mineral composition, and microstructure.

(3) Practical Application Module:The practical application of refractory materials is crucial for establishing a connection between theory and practice in industry. Acknowledging the profound impact of this phenomenon on engineering is imperative, as it highlights the importance of material properties. This, in turn, drives technological innovation and industrial advancement. This module provides a "validation ground" for understanding material performance and technological innovation demands, as well as acting as a "bridge" connecting multidisciplinary knowledge. For engineers, applying knowledge is the basis for selecting, accepting and diagnosing faults in materials. For those engaged in research and development, industrial demands are a significant driver of material innovation. For students, application cases integrate fragmented knowledge into a systematic understanding. The core objectives of this module are as follows: First, it is essential to acquire the necessary skills and knowledge to select the most suitable refractory materials for a given industrial furnace. This requires consideration of the specific operational conditions, including temperature, atmosphere, the presence of corrosive media, mechanical stress and thermal shock. Comprehending the composition of these materials, the masonry techniques employed, their intended applications, failure mechanisms and essential maintenance practices is also crucial to ensuring their durability and longevity. Key content includes: The application of material selection principles is of paramount importance in this field. A detailed analysis of typical industrial furnace applications and masonry and construction techniques is also essential, as are usage and maintenance protocols. Finally, failure mechanism analysis is a crucial

ISSN 2522-6398 Vol. 8, Issue 10: 29-34, DOI: 10.25236/FER.2025.081005

component.

2.2 Teaching Methodology: Blended Online-Offline Implementation Pathways

Educators face a significant challenge in adapting to the trend of educational informatics and developing a comprehensive, student-centred blended teaching system that seamlessly integrates course theory, practical application and modern information technology [4]. Treenity's proprietary online courses, integrated with offline resources including self-built case libraries, classroom discussions and case analysis teaching methods, effectively bridge the gap between theory and practice. Online sessions emphasize knowledge transfer and self-directed learning, while offline sessions focus on facilitating deep interaction, skill development and practical application.

(1) Online module (Treenity platform): In blended learning environments, online instruction plays a dual role: firstly, it supports student self-directed learning, and secondly, it enhances classroom interaction. The primary functions of the aforementioned institution can be categorized as follows:

First: Course resources are categorized and aligned according to 'theoretical content' and 'practical content'. Theoretical resources emphasize systematic instruction, enabling students to acquire foundational knowledge through online MOOC videos. Using the features of the Treenity platform, instructors can create online question banks, chapter quizzes and final exams to help students master the core theoretical components of the course. Practical resources emphasize project- and task-driven learning. The Wisdom Tree platform includes a 'Course Materials' section containing various professional resources related to the course, such as case studies, PowerPoint presentations, books, refractory production equipment and experimental apparatus, as well as images and videos demonstrating usage processes. Students can use this section to develop an initial understanding of, and proficiency in, refractory production and application procedures.

Second: The objective of this learning task is to design guidance on the subject. The content has been carefully designed to align with the unique features of mobile online learning. Educational material is delivered in the form of concise video segments, each lasting between 10 and 15 minutes. This approach is intended to encourage flexible student engagement and mitigate the risk of disparate and potentially ineffective knowledge acquisition. The focus is on the systematic integration of learning and managing students' fragmented learning patterns. A structured learning pathway has been devised to ensure seamless integration between online and offline classroom activities, comprising a sequence of 'online self-study-classroom internalization-post-class extension-competency enhancement'. Before the class begins, assignments including learning objectives, guiding questions and preparatory materials are distributed via the Rain classroom platform. Students are required to view the videos and take note of any points they find confusing, bearing in mind the following questions:

Third: Supporting learning processes and managing interactivity. Utilizing platform data facilitates tracking of learning behaviours (e.g. video viewing duration and test completion rates), identifying students who are falling behind and sending personalized reminders for real-time learning monitoring. Discussion threads in forums are recommended to guide student contributions and facilitate discussion. For example, threads could be created to explore the concept of refractoriness in refractory materials. Instructors provide regular feedback to assess students' knowledge levels and thinking patterns, enabling asynchronous interaction [5]. Teaching challenges should be identified based on platform data (e.g. chapter test pass rates and discussion quality) to optimize subsequent course design.

(2) The Offline Module (the Flipped Classroom approach): Offline instruction is the core component for deepening knowledge, developing skills and shaping values. It is essential that the system integrates seamlessly with online segments to create a closed-loop system in which 'online learning lays the foundation and offline sessions facilitate application.

First: Knowledge internalization and skill improvement: The primary objective of offline instruction is to transform foundational knowledge acquired through online self-study into a deep understanding that can be put into practice. This process requires a structured design to facilitate cognitive advancement. To address common challenges encountered during online learning, teachers assign inquiry-based tasks using case studies as instructional tools. Students collaborate in groups to engage in critical discussions, both within and between teams, thereby stimulating analytical, evaluative and creative thinking skills. Through guided facilitation, instructors lead students in deconstructing and thoroughly analyzing cases, helping them to synthesize knowledge and connect fragmented concepts into integrated networks. This approach strengthens knowledge learning and builds systematic frameworks. Subsequently, instructors present analogous engineering problems for

ISSN 2522-6398 Vol. 8, Issue 10: 29-34, DOI: 10.25236/FER.2025.081005

students to solve, encouraging them to progress from comprehension to creation and enhancing their cognitive abilities.

Second: Case selection and application: Cases are systematically selected and applied based on teaching objectives, students' cognitive levels and industry demands. Cases are derived from real engineering challenges or research projects that are aligned with cutting-edge technology to ensure strong relevance to the practical application of refractory materials. Furthermore, cases should be broken down into multiple specialized knowledge points, with their resolution representing the combination of these points with innovative thinking. This approach aligns with the real problems, high challenges' standard, ensuring cases are neither fragmented nor of a low level. Cases must incorporate multidimensional conflicts, such as the balancing of the impact of volumetric changes on a material's physical and chemical properties during heating. In an educational context, conflict has been shown to stimulate critical thinking and engender multiple lines of inquiry. In the above example, instructors can lead students to ask questions such as: What volumetric changes occur during the heating process? The process by which these structures form remains a subject of scientific investigation. This investigation will determine which physical and chemical property changes occur in the material. It is imperative to ascertain the underlying causes of this phenomenon. This approach cultivates students' higher-order thinking skills. The specific implementation process for case-based teaching is as follows: Prior to the commencement of the lesson, the following preparatory measures were undertaken: Structured, guided learning materials are recommended to stimulate independent enquiry. The classroom is the setting for the subsequent discussion. The focus should be on transforming skills through diverse activities to deepen understanding. Post-class: The emphasis should be placed on reinforcing skills and fostering innovation through activities such as comparing corporate solutions, analyzing existing design shortcomings, and proposing alternative solutions.

2.3 Competency Development: Enhancing Engineering Skills

In the context of contemporary reforms and developments in high education, enhancing engineering capabilities has become a key criterion for assessing the effectiveness of talent development. This focus goes beyond the traditional transfer of knowledge, aiming to provide students with a wide range of practical skills to solve complex engineering problems, drive technological innovation and adapt to industrial change. Developing this capability involves more than just accumulating individual skills, it is a systematic process of integration and spiral-shaped progression.

Firstly, it is essential to have a thorough understanding of the subject and the ability to apply this knowledge cohesively. This forms the basis of engineering competence. From the outset, students must adhere meticulously to the curriculum plan, mastering not only the core theoretical knowledge in mathematics and the natural sciences relevant to their major, but also demonstrating their ability to synthesize this knowledge and apply it to real-world engineering scenarios. Knowledge is assessed progressively through three intensive practical training sessions- -metalworking practice, introductory fieldwork and a graduation internship-combined with case-based virtual simulations. Students must develop accurate physical and mathematical models, perform rigorous calculations and analyses, and understand the scientific principles underlying various technical approaches. Throughout the four-year programme, students receive ongoing guidance in the form of regular monitoring, assessments, evaluations and faculty support. They learn with clearly defined objectives and effective methods, proactively enriching their knowledge by utilizing online resources, libraries, renowned lectures and opportunities to join faculty research teams in order to address any gaps in their learning.

Systems Thinking and the Application of Complex Problem-Solving Skills. Problems in modern engineering are usually characterized by the properties of complex systems, which typically involve numerous constraints, variables and objectives. This dimension's overarching objective is to cultivate students' abilities to comprehensively define problems, decompose structures, conduct modelling and analysis, evaluate trade-offs, and make informed decisions. This competency is developed primarily through two distinct approaches. Firstly, practical, focused sessions immerse students in real-world task scenarios, guiding them through the entire problem-solving process. This approach encourages students to take a holistic view, integrating technical, economic, environmental, social, ethical and sustainability factors in order to identify optimal or satisfactory solutions. Secondly, virtual practice environments are created using authentic professional case studies. By carefully examining these cases, students can refine their cognitive processes and improve their ability to address complex engineering problems. Teaching methods may include online Pre-emptive guided questions, offline immersive case discussions and post-class assignments involving similar cases for analytical reinforcement, thus progressively advancing competency development.

ISSN 2522-6398 Vol. 8, Issue 10: 29-34, DOI: 10.25236/FER.2025.081005

The first point to consider is the importance of teamwork and cross-cultural communication skills. Major engineering projects are usually carried out by multidisciplinary teams collaborating together. Therefore, it is essential for students to develop the ability to work effectively within such teams, including competencies such as effective communication, active listening, task allocation, collaboration and leadership. Case-based teaching has been shown to be an effective way of developing these skills. Forming distinct student groups that mirror authentic project teams facilitates the execution of all activities within a team framework. These activities include internal learning, discussions, decision-making processes, and external debates and exchanges. As a preliminary step, students undergo an initial adaptation phase under the guidance of faculty members. This phase is designed to facilitate the gradual formation of team structures. Through continuous learning, students refine collaborative mechanisms and ultimately achieve high-performing team operations.

3. The practical outcomes

This pedagogical model has been in place since 2021 and has produced favourable results over the past five years. The following table compares selected learning outcomes achieved by the 2025 cohort with those of the 2020 cohort.

Table 1: Comparison of Learning Outcomes across Different Teaching Modes in 2020 and 2025

Indicator	Traditional Model	New Model	Improvement Rate
Mastery of Fundamental Theoretical Knowledge and Concepts	75.4%	86.9%	11.5%
Complex Case Question Score Rate	57.3%	83.5%	26.2%
Post-class Assignment Excellence Rate	61.2%	89.3%	28.2%
Effective Suggestions for the Cases	1	5	400%

As shown in Table 1, comparing learning outcomes between the traditional teaching model in 2020 and the 'case-driven, three-dimensional integration' model in 2025 reveals significant improvements brought by the new approach. Firstly, the mastery rate of foundational theoretical knowledge and concepts increased by 11.5%, from 75.4% to 86.9%, indicating more effective consolidation of students' theoretical foundations. Secondly, this enhancement is evident in the application of knowledge and the development of higher-order thinking skills. The score rate for complex case questions increased notably from 57.3% to 83.5% (an increase of 26.2%), while the excellent rate for similar case assignments after class increased substantially from 61.2% to 89.3% (an increase of 28.2%). These two metrics demonstrate the enhancement in students' ability to transfer theoretical knowledge to complex real-world scenarios and solve practical problems. Furthermore, changes in students' innovative thinking are evident. The metric 'effective new suggestions provided for cases' increased from 1 under the traditional model to 5, representing a remarkable 400% improvement. These outcomes underscore the considerable merits of the 'case-driven, three-dimensional integration' model in fostering critical thinking, encouraging innovation and cultivating bespoke solutions.

4. Conclusions

The three-dimensional, interactive teaching model developed in this study addresses the challenge of abstracting professional knowledge effectively by focusing on a practical engineering case study. The programme's innovative approach integrates online and offline instruction, eliminating the traditional divide between theory and practice. Additionally, the competency dimension matrix plays a key role in developing students' complex engineering problem-solving skills effectively. Empirical evidence demonstrates that this model significantly improves students' engineering systems thinking and comprehensive innovation capabilities. The text provides essential support for paradigm shifts and practical guidance for curriculum reform and pedagogical innovation in related engineering disciplines.

Acknowledgements

The present research is financially supported by the Ministry of Education's Supply-Demand Matching Employment Education Project (No. 2024011214784), Shandong Undergraduate Teaching Reform Research Project (Z2023155), Education Reform and Development Program of Industry-Education Integration and School-Enterprise Cooperation(Cea12024027&Cea12024028) and

ISSN 2522-6398 Vol. 8, Issue 10: 29-34, DOI: 10.25236/FER.2025.081005

Shandong Province Science and Technology Small and Medium-sized Enterprises Innovation Capacity Improvement Project (2025TSGCCZZB0603 & 2025TSGCCZZB0613) and Excellent Teaching Team(2023JXTD006).

References

[1] Guo Z Q, Pan J, Zhu D Q, et al. Teaching design and practice of refractory materials courses based on the BOPPPS teaching model [J]. Journal of higher education, 2022, 8(30): 5-8.
[2] Chen Y Y, Zhang W P. Undergraduate engineering program should aim at education for engineers: outcome-basted engineering education certification and undergraduate professional orientation[J]. Journal of Architectural Education in Institutions of Higher Learning, 2019, 28(3): 63-69.
[3] Yang Y G, Wang W N, Meng B. Research on Improving Engineering Education Model Aiming at Enhancing Capacity to Solve Complicated Engineering Problems[J]. Research in Higher Education of Engineering, 2017, 65(4): 63-67.
[4] Chen N, Shao Q. Reform path and practice of blended online and offline teaching in Vegetable Cultivation course[J]. Anhui Agricultural Science Bulletin , 2025, 31(4): 132-137.
[5] Xiao X Y. Exploration and practice of online-Offline blended teaching in college english courses[J]. Open Access Library Journal, 2021, (8): 1-9.