ISSN Print: 2707-2398 Online: 2707-2401
Environment and Resource − 2026, 8(1)
https://doi.org/10.35534/er.0801017

Reform and Practice of the "Material Preparation and Processing" Course Based on the O-PIRTAS Model: Cultivating Applied Talents for Engineering Education Accreditation

Tingting Cai

Department of Chemical and Material Engineering, Lyuliang University, Lvliang

Abstract: Under the global imperative of "Green Manufacturing" traditional teaching in Material Preparation and Processing faces challenges regarding abstract processes and insufficient environmental integration. To address this, we introduce the O-PIRTAS (Objective, Preparation, Instructional Video, Review, Test, Activity, Summary) flipped classroom model, guided by Outcome-Based Education (OBE). The course was reconstructed using the "Process-Structure-Properties-Performance" four-element logic and virtual simulation tools to visualize energy-intensive mechanisms. By establishing a "Theory–Simulation–Verification" closed loop, the model effectively narrows the chasm between theoretical learning and sustainable engineering practice. Using the "Liquid Metal Forming" module as a case study, results from three teaching cycles (2022–2025) demonstrate significant improvements: core objective achievement rose to 0.81, average final scores increased by 5 points, and the proportion of high-achieving students increased by 15%. This reform effectively enhances students' comprehensive design capabilities, providing a valid paradigm for cultivating applied talents with an awareness of resource efficiency.

Key words: O-PIRTAS; Material Preparation and processing; Engineering education accreditation; Four-element logic; OBE

Copyright © 2026 by author (s) and SciScan Publishing Limited
This article is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License. https://creativecommons.org/licenses/by-nc/4.0/

1 Introduction

Materials Science and Engineering (MSE) stands as a foundational pillar supporting the national strategy of a "Manufacturing Power," playing a pivotal role in the global higher education system. However, the materials processing industry is traditionally associated with high energy consumption and significant resource depletion. In the context of global climate change and the strategic goal of "Carbon Peaking and Carbon Neutrality," the industry faces an urgent transition toward green, low-carbon, and circular development. Consequently, higher education in this field must evolve. It is no longer

Funding: This work was supported by the Teaching Reform and Innovation Project in Higher Education Institutions of Shanxi Province (J20231330) and the University-Industry Collaborative Education Program(231000682251235).
Author information: Tingting Cai, Department of Chemical and Material Engineering, Lyuliang University, associate professor.
Article Citation: Cai, T. T. (2026). Reform and Practice of the "Material Preparation and Processing" Course Based on the O-PIRTAS Model: Cultivating Applied Talents for Engineering Education Accreditation. *Environment and Resource, 8*(1), 131-136.

sufficient to teach students merely how to manufacture products; education must now cultivate engineers who possess a profound understanding of environmental sustainability, resource efficiency, and life-cycle assessment(Liu M et al., 2025).

As a core compulsory course for majors such as Material Chemistry and Metallurgical Engineering, Material Preparation and Processing covers the principles, methods, and engineering applications of metal forming technologies, including liquid forming, plastic forming, and welding. This course serves as a critical link in cultivating students' engineering thinking by establishing a closed-loop cognition of the "Process-Structure-Properties-Performance" four elements. Nevertheless, traditional teaching paradigms face severe challenges in meeting modern engineering standards. Firstly, there is a disconnect between theory and practice; traditional instruction relies on static illustrations that fail to capture dynamic, energy-intensive manufacturing processes, making it difficult for students to visualize complex spatial structures. Secondly, the "invisible" nature of microscopic mechanisms creates a cognitive barrier, preventing students from connecting macroscopic process parameters with microscopic structural evolution. Thirdly, and most critically for the environmental context, the traditional curriculum often lacks a deep integration of "Green Manufacturing" principles, failing to guide students in analyzing the environmental footprint of different processing technologies.

To tackle these predicaments and meet the requirements of Engineering Education Accreditation, the flipped classroom model has emerged as an effective transformative strategy for the implementation of Outcome-Based Education (OBE)（Jin L et al., 2023; Roche T et al., 2024; Lin ling Z et al., 2023）. The O-PIRTAS model structures the learning process into seven distinct components: Objective, Preparation, Instructional Video, Review, Test, Activity, and Summary. This model is particularly effective for engineering courses as it shifts lower-order cognitive tasks to pre-class autonomous learning, thereby liberating valuable classroom time for higher-order interactions(Guo J, 2019). This paper explores the application of the O-PIRTAS model in the reform of the Material Preparation and Processing course. We reconstructed the knowledge system based on the "Four Elements" logic and integrated virtual simulation tools to bridge the gap between theory and practice. Specifically, we emphasize how this model fosters students' ability to optimize processes for energy saving and waste reduction. Using the "Liquid Metal Forming" module as a case study, we demonstrate how O-PIRTAS transforms abstract principles into tangible, sustainable engineering skills. Through a comprehensive analysis of teaching outcomes from 2022 to 2025, this study verifies that the model significantly boosts students' comprehensive design capabilities, offering a valid paradigm for engineering education reform in the era of sustainable development.

2 The O-PIRTAS Flipped Classroom Model and Course Reconstruction

The O-PIRTAS flipped classroom model serves as a robust pedagogical framework designed to bridge the gap between abstract theoretical knowledge and complex engineering applications. While traditional flipped classrooms often focus solely on knowledge transfer, the O-PIRTAS model systematically restructures the instructional process into seven interconnected components: Objective, Preparation, Instructional Video, Review, Test, Activity, and Summary. This model is particularly instrumental for the Material Preparation and Processing course, as it effectively addresses the challenges of visualizing microscopic material evolution and integrating fragmented process knowledge.

To align with the requirements of Green Manufacturing and Engineering Education Accreditation, we fundamentally reconstructed the course content. Traditional teaching often adopts a linear "Process-Properties" approach, neglecting the critical intermediate link of "Structure" and the ultimate "Performance" in service. We expanded this into a closed-loop "Process-Structure-Properties-Performance" four-element logic system, with "Environmental Impact"

integrated as a critical decision-making criterion throughout.

As illustrated in Table 1, knowledge points are no longer isolated. When students learn a specific "Process," they are required to evaluate it from multiple dimensions:

(1) Microscopic Mechanism: How does the process alter the microstructure, such as grain refinement?

(2) Macroscopic Performance: How does this structural change enhance mechanical properties such as strength and fatigue life?

Resource Implication: Does this process improve the material's service life, thereby achieving "resource saving"? This reconstruction ensures that students cultivate a "Life-Cycle Assessment" mindset, understanding that optimizing material performance is intrinsically linked to resource conservation.

Table 1 Reconstruction of teaching content based on the "Four-Element" logic (Example: Chapter 1)

Knowledge Point	Process (Processing)	Structure	Properties	Performance & Application
Inoculation Treatment	Adding inoculants (FeSi/CaSi, 0.25%~0.6%) to molten iron.	Promotes formation of graphite nucleation cores; refines pearlite grains and graphite flakes.	Significantly improves tensile strength and hardness; reduces section sensitivity.	Suitable for heavy-duty castings like engine blocks; enhances durability and reduces material waste.
Spheroidizing Treatment	Adding Mg or Rare-earth Mg alloys to molten iron.	Graphite crystallizes into spheres, minimizing stress concentration on the matrix.	Tensile strength rivals carbon steel; excellent ductility and toughness.	Replaces expensive forged steel in crankshafts, achieving "replacing steel with iron" to save energy and costs.
Solidification Control	Using risers and chills to achieve "Directional Solidification."	Eliminates shrinkage cavities and porosity; controls grain orientation (e.g., columnar crystals).	Ensures structural density and mechanical integrity under load.	Critical for safety-critical parts; reduces rejection rates and scrap generation.

3 Classroom Design and Implementation: A Case Study on Liquid Metal Forming

To demonstrate the effectiveness of the O-PIRTAS model, we selected the "Liquid Metal Forming" module as a representative case study. Casting is a fundamental manufacturing process but is traditionally characterized by high energy consumption, significant pollution, and a "black box" nature of solidification. Therefore, this module is ideal for training students in both process design and sustainable engineering practices (Figure 1).

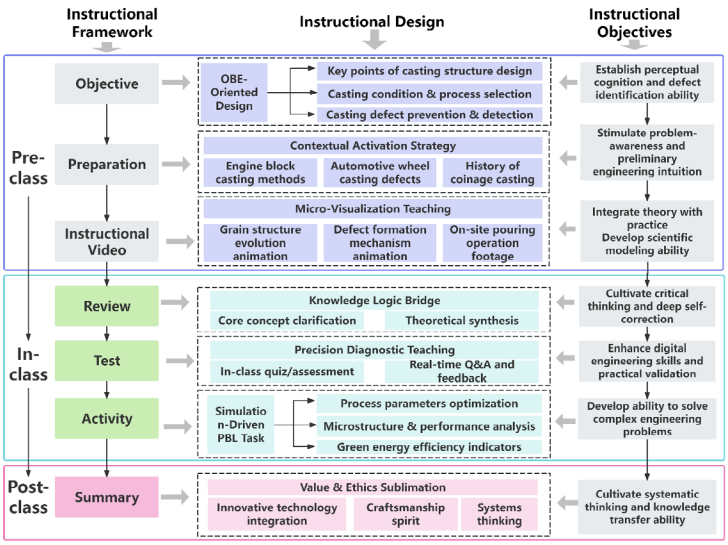

Figure 1 The framework of the O-PIRTAS flipped classroom model applied in the Material Processing course

3.1 Phase 1: Pre-class Online Learning (Knowledge Acquisition)

(1) Objective & Preparation: Students were tasked with identifying casting components in their daily lives and investigating their potential defects. A specific focus was placed on the environmental footprint of traditional foundries to trigger awareness of "Green Casting".

(2) Instructional Video: Addressing the "invisibility" of high-temperature processes, the instructor curated a library of 4D micro-simulation videos. These resources visually demonstrated grain nucleation and growth dynamics, as well as the formation mechanisms of defects like shrinkage cavities. Crucially, videos showcasing modern "Clean Production" technologies were included to contrast with outdated, polluting methods.

3.2 Phase 2: In-class Offline Interaction (Internalization & Application)

(1) Review & Test: A rapid 10-minute session bridged the online and offline phases. Through diagnostic quizzes on mobile devices, the instructor identified common misconceptions regarding solidification shrinkage versus liquid contraction, enabling precise "Just-in-Time Teaching.

(2) Activity (The Core: Simulation-Driven Green Design): This phase implemented a "Theory–Simulation–Optimization" closed-loop Project-Based Learning (PBL) activity.

(a) Scenario: Design the casting process for a "High-Pressure Flange Plate.

(b) Preliminary Design: Students calculated gating ratios and riser dimensions based on empirical formulas.

(c) Virtual Simulation: Students imported their designs into ANSYS or Pro CAST software to simulate the mold filling and solidification process. Defect Prediction: The simulation temperature field often revealed "Hot Spots" isolated from risers, predicting the formation of shrinkage porosity. Resource Analysis: In a traditional setting, discovering this defect would require casting a physical prototype, resulting in material waste and energy loss. Through simulation, students visualized this "potential waste" virtually.

(d) Optimization: Based on simulation feedback, students optimized the process by adding "Chills" to enforce directional solidification and reducing the riser volume to improve the "Casting Yield". Improving yield is a direct contribution to resource efficiency.

(3) Summary: The session concluded with a synthesis of technical and ideological points. The instructor highlighted how the optimized process not only ensured structural integrity (Craftsmanship Spirit) but also minimized material waste (Green Manufacturing). The discussion reinforced the concept that "Simulation is a key enabler of Sustainable Engineering," as it replaces physical trial-and-error with digital verification.

4 Analysis of Teaching Effectiveness

The implementation of the O-PIRTAS model has fundamentally transformed the teaching ecology of the Material Preparation and Processing course. To objectively evaluate the reform's effectiveness, we conducted a comprehensive analysis based on data from three teaching cycles (2023–2025).

Quantitative evaluation reveals a significant improvement in academic performance. As shown in Table 2, the achievement level of core course objectives has steadily risen. The achievement value for the core objective "Ability to analyze the relationship between material composition, structure, properties, and processing" increased from 0.72 before

the reform to 0.81 after the reform. Furthermore, the average final exam score rose by approximately 5 points, and the proportion of students in the high-scoring segment (above 85 points) increased by 15%. This shift suggests that the O-PIRTAS model effectively supports students in mastering complex engineering concepts.

Table 2 Comparison of teaching effectiveness metrics (Pre-reform vs. Post-reform)

Metric	Pre-Reform (2022)	Post-Reform (2024)	Improvement
Objective Achievement Degree	0.72	0.81	+12.5%
Average Final Score	73.4	78.6	+5.2 points
High Score Ratio (>85)	18%	33%	+15%
Student Engagement Rate	65%	92%	+27%
Complex Problem Solving	12% (Success rate in design Qs)	32% (Success rate in design Qs)	+20%

Qualitative feedback further supports these findings. Classroom observations indicated a marked increase in participation, with 92% of students actively engaging in group discussions and software operations during the "Activity" phase. Students reported that the integration of virtual simulation and environmental case studies made the learning process more relevant and stimulating. The "Innovation Feedback" loop has also proven effective; leveraging skills acquired in the course, several student teams won awards in national competitions such as the "Internet+" Innovation and Entrepreneurship Competition, demonstrating their ability to transfer classroom knowledge to innovative, sustainable engineering practice.

5 Summary and Conclusion

This study explores the reform of the Material Preparation and Processing course in the context of Engineering Education Accreditation. By adopting the O-PIRTAS flipped classroom model, we have successfully addressed the critical challenges of traditional teaching, such as the abstraction of process principles and the lack of environmental integration. The core contributions of this reform are the reconstruction of the knowledge logic based on the "Four Elements" and the establishment of a "Theory–Virtual Simulation–Practical Verification" closed-loop teaching mode.

The empirical results confirm that this model significantly enhances students' engagement, academic performance, and ability to solve complex engineering problems. By integrating green manufacturing principles and virtual simulation tools, the course not only improves teaching efficiency but also cultivates students' awareness of resource conservation and environmental protection. Future research and practice will focus on expanding the course's digital resource library with more immersive VR teaching modules and deepening industry-university collaboration to integrate real-world environmental challenges into classroom teaching. This reform provides a transferable paradigm for engineering courses in applied undergraduate universities, contributing to the cultivation of high-quality professionals ready to support the sustainable development of the materials industry.

References

[1] Liu M, Wu Q, Wang Y, Dou X, & Kong F. (2025). Reform and innovation of the Fundamentals of Materials Science course in the background of emerging engineering education. *Scientific Journal of Humanities and Social Sciences, 7*(9), 205-210.

[2] Jin L, Gao Y, Liu T, et al. (2023). A comparison between flipped and lecture-based course delivery of a career development programme for Chinese undergraduates. In *Counselling and career guidance in Asia* (pp. 110-126). Routledge.

[3] Roche T, Wilson E, & Goode E. (2024). Immersive learning in a block teaching model: A case study of academic reform through principles, policies and practice. *Journal of University Teaching & Learning Practice, 21*(2), 12.

[4] Linling Z & Abdullah R. (2023). The impact of the COVID-19 pandemic on the flipped classroom for EFL courses: A systematic literature review. *SAGE Open, 13*(1), 21582440221148149.

[5] Guo J. (2019). The use of an extended flipped classroom model in improving students' learning in an undergraduate course. *Journal of Computing in Higher Education, 31*(2), 362-390.