Engineering Education Review

RESEARCH

Curriculum Reform for Graduate Materials Forming: A Mixed-Methods Case Study

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ABSTRACT

Engineering graduate students face increasing employment pressure in the Industry 4.0 era, as industries prioritize applied competence over purely theoretical expertise. This study identifies insufficient practical experience as the central problem limiting graduates' workplace readiness. Empirical data from 52 graduate students across two cohorts show that only 26.9% of participants considered the curriculum closely aligned with engineering practice, and approximately 70% reported limited discussion of cutting-edge industrial applications in class. Key causes include a theory-centered curriculum, verification-focused laboratories, and single-mode summative assessment. Based on the course *Plastic Deformation of Metals and Alloys* as a case, which enrolls students from Materials Science and Engineering, Materials and Chemical Engineering, and Mechanical Engineering, this mixed-methods study proposes a three-pronged framework: curricular enrichment, pedagogical diversification, and multi-faceted assessment, to translate abstract knowledge into applied capability. Strategies include interdisciplinary industry-linked modules, flipped and project-based learning with simulation labs and industry projects, and a blended evaluation scheme combining formative checkpoints and summative outputs. Following the diagnostic findings, a preliminary version of this framework was implemented in the subsequent academic year, and post-implementation survey data from 31 students provide preliminary evidence that the measures strengthened students' perceived connection between course theory and industrial practice. The study offers an evidence-based diagnosis, a theory-driven reform design, and preliminary before-after implementation data showing gains across key perception dimensions, providing a design reference that other similar courses may adapt to their own contexts.

Keywords: curriculum reform, industry-education integration, mixed-methods research, engineering education, materials forming

INTRODUCTION

The Fourth Industrial Revolution (Industry 4.0) has reshaped manufacturing through automation, digitalization, and increasingly interconnected production systems. In graduate engineering education, however, a persistent concern is that advanced theoretical training is not always accompanied by sufficient opportunities to apply knowledge in authentic engineering settings. This mismatch becomes particularly visible when graduates enter industrial roles that require problem solving, technical communication, and the practical use of disciplinary knowledge (González-Pérez & Ramírez-Montoya, 2022).

Changes in engineering employment make this issue more pressing. Employers increasingly value digital literacy, adaptability, and cross-functional problem solving, while university training can remain strongly theory-oriented (Du Plessis et al., 2024; Tee et al., 2024). For graduates moving into manufacturing and industrial research and development (R&D), the ability to connect academic knowledge with production problems there-

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fore becomes an important part of workplace readiness.

Against this backdrop, this study examines the course *Plastic Deformation of Metals and Alloys*, offered by a university School of Materials Science and Engineering. The course provides a useful setting for examining how a theory-centered graduate course connects disciplinary knowledge with engineering practice. Using questionnaires and semi-structured interviews, the study identifies difficulties in course content, practical learning opportunities, classroom interaction, and assessment.

The survey and interview findings were then used to develop course-level reform proposals, including interdisciplinary application modules, an enterprise case repository, structured interactive learning, and a multidimensional assessment scheme. Following the diagnostic study, the course instructor implemented a preliminary version of these measures in the subsequent academic year, and the present paper reports both the diagnostic findings and the preliminary post-implementation feedback from students.

The study therefore has a deliberately bounded purpose. As an exploratory case study of one core course in the materials-forming direction, it does not seek statistical generalization to all graduate engineering programs. Instead, it offers a context-dependent diagnosis, a theory-driven reform design, and preliminary evidence from one implementation cycle, which may be useful for courses with similar disciplinary and industry-facing objectives.

LITERATURE REVIEW

Across conceptual, practical, institutional, and external domains, scholars have presented strategies to address the challenges of graduate employment while balancing industrial progress. Graham (2018), however, finds that the majority of the ideas are theoretical and do not include curriculum-level changes to improve hands-on skills and work preparedness.

Engineering Education Philosophy

Recent research on engineering education reform indicates that talent cultivation urgently requires a paradigm shift from passive adaptation to proactive leadership. This transformation demands that universities actively shape industrial transformation. With this background, scholars advocate for a value-oriented educational model that integrates theoretical rigor with practical applicability. For example, Brink et al. (2025) further suggest that curricula should be designed with agility and student-centered flexibility to respond to rapid industrial change. Meanwhile, Ferreira et al. (2024) highlight that multiple stakeholders call for programmes that embed professional values and industry alignment as core components of engineering training. González-Pérez and Ramírez-Montoya (2022) similarly endorse this concept, proposing the student-centered, interdisciplinary framework of Education 4.0 as a concrete pathway for achieving this transformation.

These domestic views correspond with international Education 4.0 scholarship emphasizing student-centered learning and interdisciplinary competency development (González-Pérez & Ramírez-Montoya, 2022; Srivani et al., 2022). The Higher Education 4.0 paradigm requires integrating ethics, creativity, and collaboration into engineering education. Oliveira and De Souza (2022) emphasize that while cultivating core technical skills, enhancing students' adaptability and digital literacy is equally important. Recent studies further support the integration of professional values into engineering curricula, arguing that faculty must reconsider their conceptions of engineering education to meet evolving industry needs (Beagon & Bowe, 2023). Collectively, these theoretical foundations form the bedrock of innovative educational approaches, whose core lies in prioritizing knowledge application and societal relevance. However, the lack of adequate practical research assignments in the current curriculum suggests that there is still a need to translate relevant theoretical perspectives into effective teaching strategies for productive classrooms.

Curriculum Models and Pedagogical Innovation

In addressing the persistent mismatch between engineering education and employment, recent research highlights the importance of curriculum and pedagogical reform that bridges academic learning with workplace practice. Tee et al. (2024) assert that, in the Industry 4.0 era, students' employability depends on curricula that foster digital literacy, problem-solving abilities, and adaptability via authentic experiential learning. Alogla (2026) similarly argues that engineering programs must redesign curricula around sustainable career trajectories, integrating cross-disciplinary and industry-linked experiences. Zhan et al. (2026) further demonstrate that improving the measurement and focus of employability in engineering education requires curriculum structures and pedagogies that reflect real-world work demands. Together, these findings strengthen the call for engineering education systems to align with contemporary employment realities.

The success of teaching innovations, such as flipped classrooms and project-based learning, in enhancing students' applied skills has been proven (Al Mamun et al., 2022; Baig & Yadegaridehkordi, 2023; Suárez et al., 2021). In particular, engineering students have been found to benefit greatly from the flipped classroom

model, which significantly boosts engagement and enhances teamwork and problem-solving skills, especially when combined with active, hands-on learning (Baig & Yadegaridehkordi, 2023). Research also emphasizes that using experiential teaching methods, like industry case studies and real-world simulations, during instruction helps students better understand complex systems and think creatively (Suárez et al., 2021). Consequently, López-Pérez et al. (2011) proposed a competency-based assessment system that integrates written reports, practical projects, and outcome presentations to evaluate graduate students' abilities. Together, these findings support the value of blended, integrative, and professional course models, showing their direct relevance in addressing the urgent skill demands of the Industry 4.0 era.

Industry Collaboration and External Environment

Beyond educational reforms, structural and governmental factors also play a significant role in connecting education and employment. Zhuang and Zhou (2023) emphasize that effective industry-academia collaboration requires a clear institutional framework and active participation to keep academic programs aligned with the evolving demands of the labor market. Likewise, recent evidence further reveals that effective collaboration and policy incentives significantly boost graduate employability and institutional innovation (Hossen et al., 2025; Huang et al., 2025). Collectively, these structural reforms highlight the importance of aligning educational policies with industrial transformation and encourage higher education systems to cultivate adaptable graduates with innovation-oriented skills. These findings agree with global research, which consistently emphasizes the critical role of industry-academia collaboration in improving graduate employment (Du Plessis et al., 2024; Shah & Gillen, 2024).

Also, international research effectively corroborates these findings. For example, the World Bank (2023) and the United Nations Educational, Scientific and Cultural Organization (UNESCO, 2021) both point out that incorporating digital literacy and learning by doing into higher education programs is essential for reducing skills mismatches. Recent studies (e.g., Tee et al., 2024) also show that these collaborations lead to positive results, such as increased employability, better problem-solving skills, and stronger leadership abilities among students. In short, the existing evidence suggests that successful educational reform depends on collaboration among educational institutions, industry partners, and government.

While prior research has provided theoretical frameworks for engineering education reform, its practical application remains constrained. Traditional graduate programs continue to emphasize theoretical accomplishments over practical competencies, viewing the primary objective of graduate training as cultivating academic researchers rather than industry practitioners (Beagon & Bowe, 2023). However, graduates must have both strong theoretical knowledge and practical application skills due to the Industry 4.0 era's rapid technological evolution. The gap between theoretical instruction and real-world application has become a major issue in modern education, according to employment data and international analyses (González-Pérez & Ramírez-Montoya, 2022; Ministry of Education of the People's Republic of China, 2024; Tee et al., 2024).

COURSE INTRODUCTION

The *Plastic Deformation of Metals and Alloys* is a mandatory course for chemical and materials engineering students, building upon their prior knowledge from courses like *Principles of Material Forming* and *Fundamentals of Materials Science*. The curriculum is primarily theoretical, designed to provide students with a foundational understanding of the core principles governing metal plastic deformation. Key topics include the constitutive equations for plastic deformation, yield criteria, stress-strain relationships, and the theory behind key metal strengthening techniques. The course also covers the evolution of microstructure during deformation and its theoretical impact on material properties (as detailed in Table 1). Although the curriculum also outlines practical engineering applications of metal forming, these are treated mainly as illustrative extensions of theoretical models rather than as opportunities for applied practice or industrial problem solving.

Table 1: Course Arrangement for *Plastic Deformation of Metals and Alloys*

Class hour	Modes of instruction	Content of courses
1	Classroom teaching	The crystal structure of metals and alloys
2	Classroom teaching	Crystal defects and dislocation theory
3	Classroom teaching	The microscopic mechanism of alloy plastic deformation
4	Classroom teaching	Microstructure evolution during the plastic deformation of alloys
5	Classroom teaching	Research progress in metal plastic forming
6	Classroom teaching	Stress analysis and strain analysis
7	Classroom teaching	The physical property equation of metal plastic deformation
8	Classroom teaching	The macroscopic laws of metal plastic processing

RESEARCH METHODS

This study takes the core graduate course *Plastic Deforma-*

Table 2: Mapping Between Theoretical Constructs, Questionnaire Items, Interview Questions, Findings, and Reform Measures

Theoretical Lens	Questionnaire Items	Interview Questions	Empirical Finding	Reform Measure
Situated Learning Theory	Q5 curriculum-industry connectedness; Q6 demand for practical components; Q7 hands-on task exposure	I2 theory-practice emphasis; I3 impact of lacking practice evaluation; I4 challenges of real defect analysis tasks	26.92% (n = 14) perceive close content-practice alignment; 53.85% (n = 28) have no or little hands-on experience; industrial case analysis 59.62% (n = 31), on-site investigation 50.00% (n = 26)	Cross-application module; software internship week; enterprise case repository; on-site research
Constructivist Learning Theory and ZPD	Q10 usefulness of academic discussion	I2 theory-practice emphasis; I6 ideal academic thinking cultivation	55.77% (n = 29) find discussion helpful; discussion helpfulness correlates with value guidance recognition $r = 0.78$, $p < 0.01$	Pre-class mind map; in-class group discussion
CIPP Evaluation Model	Q8 demand for staged evaluation; Q9 writing difficulties	I1 pros and cons of paper-only assessment; I5 confusion without proposal and mid-term reporting	32.69% (n = 17) want staged evaluation while 50.00% (n = 26) do not; 55.77% (n = 29) face unclear research methods; 40.38% (n = 21) report insufficient innovation exploration	Topic database; practical task section; optional proposal and mid-term reporting; innovation section
Value Education and Professional Identity	Q11 attention to national applications; Q12 value guidance; Q13 industrial-contribution willingness	I7 awareness of bottleneck technologies; I8 balance between national strategy and personal interest	59.62% (n = 31) endorse value guidance; 53.85% (n = 28) willing to engage with industrial contribution; 21.15% (n = 11) continuously follow national applications	Industrial contribution analysis task; innovation section

tion of Metals and Alloys in the materials forming direction of a Chinese university as the research case. The survey covered all graduate students enrolled in the course across the 2024 and 2025 intakes who had completed the course, and 52 valid questionnaires were finally collected, including 16 students majoring in Materials Science and Engineering and 36 students majoring in Materials and Chemical Engineering. Meanwhile, 16 students were selected for semi-structured interviews.

Theoretical Framework and Operationalization

The questionnaire items and interview questions were derived from four theoretical perspectives: Situated Learning Theory, Constructivist Learning Theory and the Zone of Proximal Development, the CIPP (Context, Input, Process, Product) evaluation model, and value education and professional identity. Each perspective was operationalized into specific items so that the analysis is theory-based rather than purely descriptive; Table 2 presents the complete mapping between theoretical perspectives, instrument items, interview questions, and the corresponding findings and reform measures. This four-perspectives framework also defines the analytical pathway of the study, ensuring that the diagnosis, findings, and proposed reform measures all trace back to explicit theoretical constructs.

Questionnaire Survey

The questionnaire focuses on three key areas: enhancing engineering practical skills, overcoming the limitations of single-criterion evaluation, and integrating current development trends. It applies a three-tiered framework to all enrolled students, using standardized measures for status diagnosis, needs assessment, and reform direction (Figure 1). This approach provides clear guidelines for course optimization, quantitatively identifies issues such as inadequate industry-education integration and narrow assessment methods, and systematically gathers data to improve the course evaluation system. The questionnaire was pre-tested with 3 students before formal distribution, and the item wording was optimized based on feedback. Reliability analysis showed a Cronbach's α coefficient of 0.899, indicating high internal consistency. The Kaiser-Meyer-Olkin (KMO) value was 0.906, and Bartlett's test of sphericity was significant ($p < 0.001$), demonstrating good construct validity. Descriptive statistics, cross-tabulation analysis, one-way analysis of variance (ANOVA) and Pearson correlation analysis were employed for data processing.

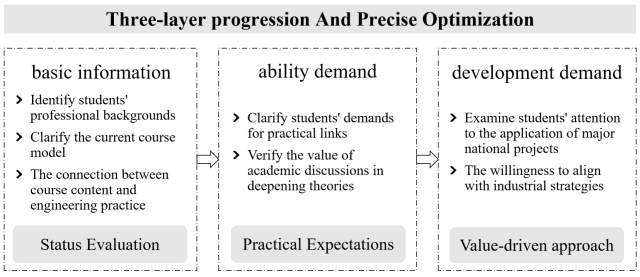


Figure 1. Schematic diagram of the questionnaire structure

Exploratory factor analysis extracted two factors explaining a cumulative 68.24% of the total variance (see Table 3). Pearson correlations revealed several meaningful associations among perception, value, and willingness variables (see Table 4). Regression analyses showed that perceived rationality of evaluation predicted learning-outcome reflection, R squared = 0.510, and that value guidance was the only significant predictor of industrial-contribution willingness, R squared = 0.470 (see

Table 3: Factor Loadings after Rotation in Exploratory Factor Analysis

Item	Factor 1 Course-and-Assessment Perception	Factor 2 Process-Assessment and Frontier Awareness	Communality
Q2 Perceived rationality of evaluation	0.84		0.722
Q4 Comprehensiveness of learning-outcome reflection	0.85		0.757
Q5 Curriculum-industry connectedness	0.82		0.705
Q7 Hands-on task exposure	0.51		0.360
Q10 Usefulness of academic discussion	0.87		0.771
Q12 Endorsement of value guidance	0.86		0.799
Q13 Industrial-contribution willingness	0.73		0.643
Q8 Demand for staged evaluation		0.86	0.740
Q11 Attention to national engineering applications		0.74	0.645
Eigenvalue after rotation	4.50	1.64	
Variance explained after rotation	50.01%	18.23%	
Cumulative variance explained	68.24%		

Table 4: Pearson Correlation between Variables

Variable pair	*r*	*p*
Perceived rationality of evaluation–comprehensiveness of learning-outcome reflection	0.71	< 0.01
Curriculum-industry connectedness–hands-on task exposure	0.36	< 0.01
Curriculum-industry connectedness–industrial-contribution willingness	0.65	< 0.01
Usefulness of academic discussion–endorsement of value guidance	0.78	< 0.01
Usefulness of academic discussion–industrial-contribution willingness	0.57	< 0.01
Attention to national engineering applications–industrial-contribution willingness	0.45	< 0.01
Attention to national engineering applications–endorsement of value guidance	0.41	< 0.01

Table 5: Regression Analysis Results

Predictor	*B*	*t*	*p*	VIF
Model 1: DV = comprehensiveness of learning-outcome reflection				
Constant	1.07	3.98	< 0.001	
Perceived rationality of evaluation	0.69	7.21	< 0.001	1.00
Model fit: R squared = 0.510, adjusted R squared = 0.500, $F(1, 50) = 52.028$, $p < 0.001$				
Model 2: DV = industrial-contribution willingness				
Constant	0.24	0.54	0.589	
Hands-on task exposure	0.10	0.61	0.543	1.32
Attention to national engineering applications	0.26	1.69	0.098	1.30
Endorsement of value guidance	0.56	4.43	< 0.001	1.33
Model fit: R squared = 0.470, adjusted R squared = 0.437, $F(3, 48) = 14.207$, $p < 0.001$				

Table 5). One-way ANOVA found no significant between-major differences on any rating-scale item, with negligible to small effect sizes (see Table 6). The psychometric analyses confirm the reliability and structural validity of the survey, the regressions reveal that value guidance, rather than prior practice exposure, is the decisive driver of industrial-contribution willingness, and the effect sizes of all between-major comparisons remain negligible, collectively offering empirical support for the design and prioritization of the reform measures.

Semi-structured Interviews

As shown in Figure 2, the overall framework was developed during the semi-structured interview phase, focusing on identifying learning barriers, restructuring course models, and aligning strategic needs. Sixteen students were selected for interviews using stratified sampling by grade and major, ensuring representation

Table 6: One-Way ANOVA between the Two Professional Groups*

Rating-scale item	Mean MSE / Mean MCE	*F*(1, 50)	*p*	Partial eta squared
Q2 Perceived rationality of evaluation	2.50 / 2.53	0.006	0.941	0.000
Q4 Comprehensiveness of learning-outcome reflection	2.50 / 2.56	0.035	0.852	0.001
Q5 Curriculum-industry connectedness	2.44 / 2.61	0.173	0.679	0.003
Q7 Hands-on task exposure	2.56 / 2.92	0.983	0.326	0.019
Q8 Demand for staged evaluation	3.31 / 3.11	0.292	0.592	0.006
Q10 Usefulness of academic discussion	2.75 / 2.28	2.278	0.138	0.044
Q11 Attention to national engineering applications	2.50 / 2.56	0.019	0.890	0.000
Q12 Endorsement of value guidance	2.50 / 2.56	0.018	0.894	0.000

Note: ** n = 16 for Materials Science and Engineering, n = 36 for Materials and Chemical Engineering, MSE = Materials Science and Engineering, MCE = Materials and Chemical Engineering*

across different academic backgrounds. Open-ended discussions and a progressive questioning technique were used to gather qualitative data, with each interview lasting 10–20 minutes and fully transcribed with consent. A three-level coding procedure (open coding, axial coding, selective coding) was adopted for text analysis, and double coding by two researchers was performed to control bias. Data saturation was achieved after the 14th interview, with no new core themes emerging. This approach aimed to overcome the limitations of quantitative data and provide a foundation for comprehensive decision-making in future curriculum reforms by uncovering students' hidden needs and intrinsic motivations, aspects that the survey questionnaire could not fully address.

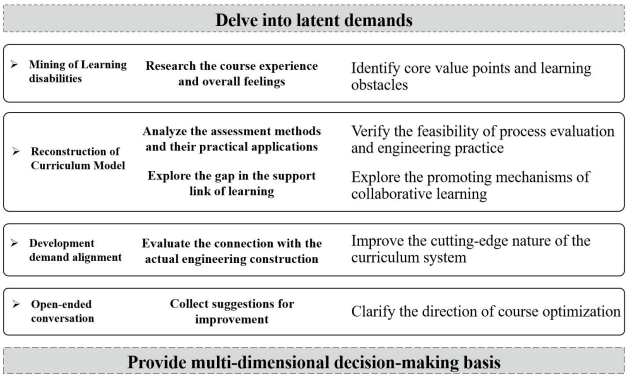


Figure 2. Semi-structured interview guide structure diagram

The questionnaire and interview data together provide an exploratory mixed-methods basis for identifying curricular weaknesses and informing reform design, with interviews explaining the meanings underlying the quantitative patterns rather than compensating for the limited sample size. Following the diagnostic survey and interviews, the course instructor implemented a subset of the proposed reforms in the subsequent academic year, including industry expert lectures, structured group discussions, frontier topic seminars, and mid-term feedback sessions for course papers. Students also participated in a field visit to a local metal additive manufacturing enterprise, where they observed industrial 3D printing equipment, laser repair and remanufacturing processes, and aerospace component production lines. To evaluate the preliminary effects of these measures, a post-implementation survey using the same core items was administered to the students enrolled in the reformed course, and follow-up semi-structured interviews were conducted with a subsample. The pre-post comparison is reported in Section "***Post-implementation Evaluation: Preliminary Evidence***".

RESULTS

This section presents the findings in three areas: course content, teaching strategies, and course evaluation, all based on survey data, interview transcripts and classroom records.

Course Content: The Dilemma of Balancing Theory and Practice

The course on *Plastic Deformation of Metals and Alloys* focuses primarily on theoretical foundations, covering fundamental models, microstructural mechanisms of deformation, and strengthening principles. Classroom case studies tend to emphasize conventional, textbook examples of plastic forming in legacy production settings rather than contemporary applications involving digital control, process optimization, or multi-material assemblies. Empirical data corroborate this orientation: only 26.92% of surveyed students ($n = 14$) consider the course content closely aligned with real-world engineering needs (see Figure 3), and over half reported limited exposure to cutting-edge industrial cases in class. Consequently, students' mastery is often limited to foundational principles without a clear understanding of how those principles inform complex, modern engineering problems. Cross-analysis by major shows noticeable dif-

ferences in practical demands: students majoring in Materials Science and Engineering show higher demand for virtual simulation experiments, while students majoring in Materials and Chemical Engineering prefer on-site enterprise investigations. To bridge this gap, the course needs targeted redesign: deepen applied modules that map theory to industrial scenarios, enrich laboratory work with process-relevant experiments or simulations, and update case studies to reflect contemporary manufacturing technologies and diagnostic tasks.

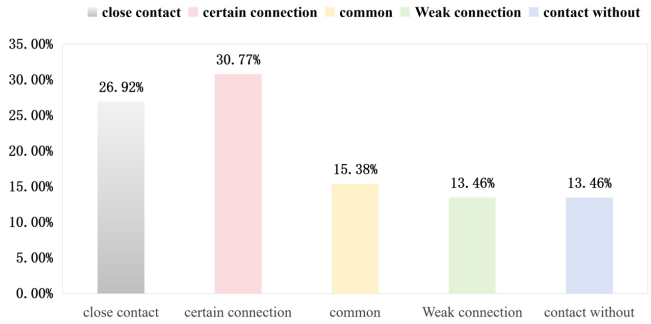


Figure 3. The degree of connection between the course and the practice

Furthermore, 53.85% of students (n = 28) had no or little hands-on experience applying the theory to practical industrial problems. Additionally, most students expressed a desire for more practical teaching elements, such as corporate research, software simulation, and industrial case studies (see Figure 4). This indicates a significant gap in practical education within the current curriculum. Such a gap limits the effectiveness of hands-on learning by disconnecting education from real-world engineering needs and hindering the development of students' practical skills.

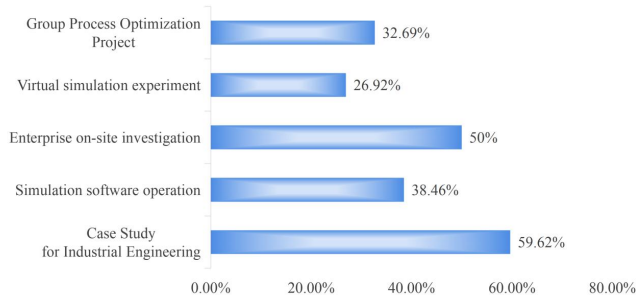


Figure 4. Expected increase in practical activities

Teaching Methods: From One-way Instillation to Multi-dimensional Interaction

Currently, lecture-based instruction is the primary method used in the *Plastic Deformation of Metals and Alloys* course. While this approach effectively conveys theoretical knowledge with logical clarity, it does not foster essential skills such as "proactively analyzing problems and collaborating on solutions in practical contexts". These practice-oriented competencies are crucial given the evolving job market for specialized graduate students, and cannot be developed through a lecture-focused approach that solely emphasizes theoretical content.

Several students mentioned in interviews that purely theoretical instruction does not adequately encourage students to connect concepts with real-world engineering problems. This is why lectures often feature "stuck questions and silent discussions", rather than issues with theoretical understanding. Additionally, the survey results show that 55.77% of students (n = 29) believe class discussions help them understand the practical application of theory, while 34.62% (n = 18) report limited or no benefit (Figure 5). This highlights that the current lecture-centered format fails to meet students' expectations of linking academic inquiry with industry practice through collaborative exploration.

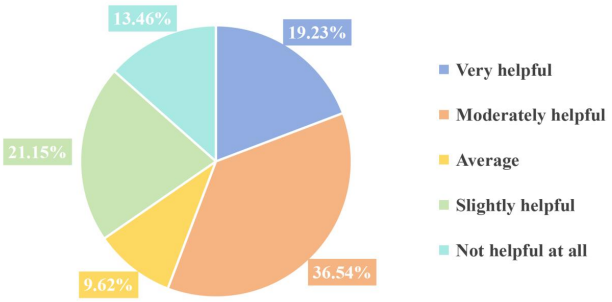


Figure 5. The assistance of academic discussions to the understanding of theories

Additionally, conventional case studies in the classroom do not expose students to the latest industry advancements, preventing them from fully understanding the course's significance and hindering their professional confidence. Survey results show that only 21.15% of students (n = 11) pay continuous attention to the application of course theories in major national projects like high-speed rail and aviation (Figure 6). Furthermore, a large portion of students suggested increasing the course's focus on technological innovation. This indicates the need for the course to better align professional knowledge with industry demands and to include more value-driven content.

Correlation analysis shows that perceived helpfulness of academic discussions is significantly positively correlated with recognition of value guidance (r = 0.78, p < 0.01), indicating that high-quality interactive teaching can simultaneously promote theoretical understanding and value identity.



Figure 6. The application of course-related theories in engineering practice

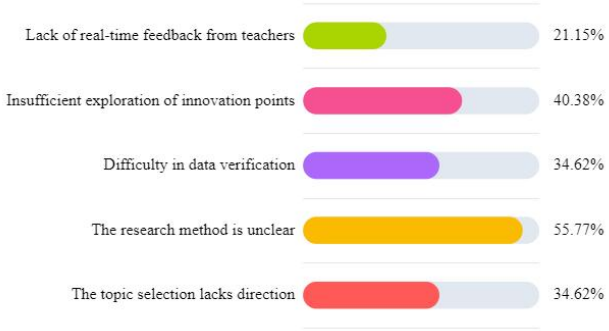


Figure 8. The problems encountered in the course assessment tasks

Evaluation Method: From Single Paper to Multidimensional Examination

Currently, assessment relies solely on course papers, overlooking important aspects of students' overall skills. Data indicate that students reported that paper-based assessment improved their theoretical knowledge organization ability by 51.92% (n = 27) but enhanced their engineering practice ability by only 25.00% (n = 13) (Figure 7). This suggests that the current assessment method inadequately reflects students' comprehensive competencies, particularly in evaluating practical skills, which are a key objective.

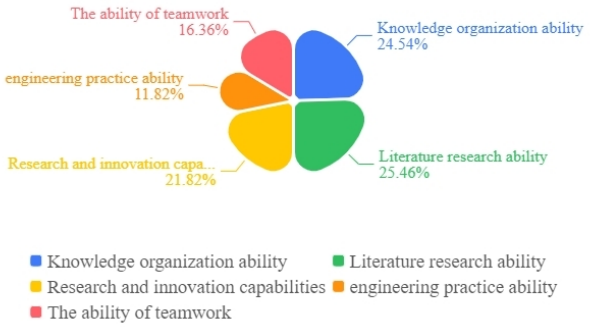


Figure 7. Course assessment for ability improvement

Additionally, we found that the course does not monitor students' learning progress over time or offer varied assessment methods. Among the 16 interviewees, over 70% reported that questions during mid-term presentations helped them identify gaps in their learning. 40.38% of students (n = 21) reported insufficient exploration of innovative points in course papers, and 55.77% (n = 29) faced unclear research methods, and more than half stated that their papers did not explore new ideas in sufficient depth (Figure 8). This suggests that fostering student growth requires a process-oriented assessment approach.

Notably, attitudes toward phased evaluation are highly differentiated: students who struggle with topic selection are more supportive of adding mid-term presentations and proposal sessions, while students who are dissatisfied with the current evaluation and lack teacher feedback are more resistant to additional assessment links.

Post-implementation Evaluation: Preliminary Evidence

Following the diagnostic survey and interviews, the course instructor implemented a preliminary version of the proposed reforms in the subsequent academic year. The measures included industry expert lectures delivered by engineers from a local metal additive manufacturing enterprise, covering high-temperature alloy selective laser melting for aero-engine components, titanium alloy laser deposition for precision structural parts, and spacecraft protective gradient materials; a half-day field visit to the enterprise facility where students observed metal 3D printing equipment and laser cladding repair processes; structured in-class group discussions focused on the practical challenges introduced by the expert; and optional mid-term feedback sessions. As part of these activities, students observed the metal laser powder bed fusion process in operation on site (Figure 9), and attended the industry expert lecture introducing current metal additive manufacturing research and applications (Figure 10).

To evaluate the preliminary effects, the same core questionnaire items were administered to 31 students enrolled in the reformed course. The internal consistency of the post-implementation survey was acceptable, Cronbach's α = 0.768. Table 7 compares the pre-reform diagnostic data (n = 52) with the post-implementation data on key perception items.

The most pronounced improvement was observed in students' perceived awareness of industry frontiers, which rose from 21.15% to 93.55%, likely reflecting the direct impact of the frontier lectures and the enterprise field visit. Perceptions of whether the assessment system

Table 7: Pre-Post Comparison of Key Perception Items

Item	Pre-reform (n = 52)	Post-implementation (n = 31)	Change
Course content connected to engineering practice	26.92%	80.65%	+53.73 pp
Adequate hands-on or simulation opportunities	46.15%	90.32%	+44.17 pp
Industry case lectures helpful for theory understanding	—	80.64%	Newly measured
Classroom group discussions deepen understanding	55.77%	83.87%	+28.10 pp
Frontier lectures inform students of industry development	21.15%	93.55%	+72.40 pp
Mid-term feedback effectively improves course papers	—	67.74%	Newly measured
Assessment enhances engineering practice ability	25.00%	74.20%	+49.20 pp
National engineering cases strengthen professional responsibility	59.62%	80.65%	+21.03 pp
Willingness to align career with national industrial needs	53.85%	74.19%	+20.34 pp
Assignments help apply theory to real problems	—	77.42%	Newly measured

Note: *pp = percentage points.*



Figure 9. Students observing the metal laser powder bed fusion process during the field visit to an additive manufacturing enterprise

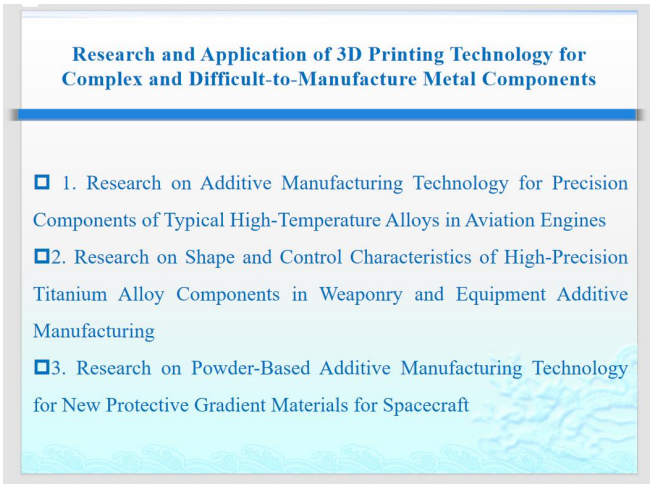


Figure 10. Industry expert lecture on advanced metal additive manufacturing, covering high-temperature alloy precision components for aero-engines, titanium alloy additive manufacturing, and spacecraft protective materials

enhances engineering practice ability nearly tripled, from 25.00% to 74.20%, suggesting that the introduction of practical task components and mid-term feedback addressed a clearly identified weakness. The proportion of students perceiving a close link between course content and engineering practice rose from 26.92% to 80.65%. Overall, 58.06% of students reported being very satisfied with the course and an additional 19.35% reported being fairly satisfied, yielding an overall satisfaction rate of 77.41%. A small minority of students remained dissatisfied (3.23% very dissatisfied and 16.13% somewhat dissatisfied), suggesting that the reform measures have not yet fully addressed all student needs. Open-ended feedback indicated that the industry case lectures and field visit were the most appreciated components, while some students noted that the case content remained concentrated on additive manufacturing and did not yet cover traditional forming processes such as stamping and forging in equal depth.

DISCUSSION

The findings reveal a pronounced mismatch between theoretical instruction and practical application in *Plastic Deformation of Metals and Alloys*, a core course tailored to the university's advantageous materials forming direction. As graduate specialized courses are highly aligned with institutional disciplinary features, this study takes the course as an exploratory case and structures the discussion around three interrelated interventions: curricular enrichment, pedagogical diversification, and assessment redesign. Each intervention is grounded in empirical findings and guided by established educational theories, aiming to translate abstract knowledge into workplace-relevant competence.

Table 8: Curriculum Content Reform Plan

Suggestions	Concrete Measure	Theoretical Foundation	Anticipated Goal	Support Rate	Source
Add a cross-application module	Introducing relevant theories from cutting-edge fields. Integrating the latest production cases.	Situated Learning Theory (learning is embedded in authentic industrial scenarios to promote knowledge transfer) Motivation Theory (external industry-related content triggers students' internal learning willingness and arouses course learning interest)	Stimulate students' interest	53.85% (n = 28) lack hands-on experience; 26.92% (n = 14) perceive close link	Q7 and Q5
Embedded Software Internship Week	Learn simulation software. Conduct virtual simulation experiments.	Situated Learning Theory	Building a bridge between knowledge and action.	38.46% (n = 20)	Q6 simulation software operation
Establish an enterprise case repository	Host lectures by industry experts. Analyze real-world industrial case studies.	Industry-academia collaboration (schools and enterprises share resources, invite frontline engineers to deliver lessons and supply real-world engineering cases for classroom teaching)	Understand real-world engineering problems	59.62% (n = 31)	Q6 industrial case analysis
Carry out on-site research	Observe the production process on-site.	Constructivism (hands-on practical tasks support active knowledge construction) contextualized practice (carry out learning inside the real-life production background and combine study with on-site environment) Dewey's "learning by doing" (knowledge originates from practice, students gain cognition of industrial sites through on-site investigation and hands-on experience)	Experience the industrial production site	50.00% (n = 26)	Q6 on-site enterprise investigation

Curricular Enrichment: Bridging Theory and Industrial Contexts

Consistent with the survey results, only 26.92% of students (n = 14) perceive a close link between course content and real engineering practice, and most cases remain limited to traditional industrial scenarios. The current distribution of teaching materials, instructional design, and assessment methods in the *Plastic Deformation of Metals and Alloys* course aligns with the traditional engineering graduate program's goal of strengthening students' theoretical understanding of plastic forming and developing the analytical skills needed for academic research or industrial technical roles. However, more graduates are now pursuing engineering technology and R&D positions in the aerospace and new energy vehicle industries, where they must apply plastic forming theory to solve practical engineering problems such as lightweight stamping for power battery casings and flaw detection in aerospace titanium alloy components.

Situated Learning Theory helps explain this pattern. Knowledge is more readily transferred when learners encounter it in contexts resembling its eventual use. In the present course, topics such as simulation analysis, defect prediction, and intelligent control are only weakly connected to plastic-deformation theory, while engineering decisions involving process selection, parameter optimization, and interdisciplinary trade-offs receive limited attention. Students therefore encounter many concepts primarily as disciplinary knowledge rather than as tools for analyzing production problems. The issue is not that theoretical content is unnecessary; rather, the course offers too few structured opportunities to use that content in realistic engineering situations.

A significant challenge in engineering education today is the lack of real-world experience. To address this, Ke et al. (2024) propose a model of postgraduate training that integrates university-enterprise joint projects, emphasizing collaborative frameworks, project-based learning opportunities, and capability development through real industry tasks. This does not imply a fundamental flaw in the original curriculum design but rather emphasizes the need for stronger practical alignment.

Cross-major analysis further reveals differentiated demands: students majoring in Materials Science and Engineering show higher demand for virtual simulation experiments, while those majoring in Materials and Chemical Engineering prefer on-site enterprise investigations. Moreover, students lack firsthand exposure to industrial production challenges through field research, production line practice, or internship opportunities, which also hinders the development of effective university-industry collaboration.

Targeted at the above problems and grounded in the survey findings, the following reform measures are proposed (see Table 8). For example, an enterprise case repository is built to meet the demand of 59.62% of students for more industrial case analysis; differentiated practical modules are designed according to major-spe-

Table 9: Teaching Method Reform Plan

Stage	Concrete Measure	Theoretical Foundation	Anticipated Goal	Support Rate	Source
Activities before class	Release Classroom Mind Map	Systematic Understanding (sort out the whole knowledge framework by pre-class mind map, build systematic and complete cognition of course knowledge points)	Solidify the knowledge foundation	34.62% (n = 18) report lack of topic direction	Q9
In-class activities	Organize group discussions	Constructivist Learning Theory (students carry out group-based communication and independent thinking, actively absorb and process knowledge to finish knowledge internalization)	Promote knowledge internalization	55.77% (n = 29) find discussions helpful	Q10
Post-class	Host cutting-edge lectures	Situated Learning Theory (frontier cases and industry lectures enhance contextual perception)	Staying abreast of cutting-edge technologies	21.15% (n = 11) continuously follow national applications; 57.69% occasionally follow or have heard of them	Q11
	Assign the task of conducting an industrial contribution analysis	Social Identity Theory (students complete industrial-contribution analysis tasks, recognize the value of the major engineering theory for industrial development and establish professional identity)	Appreciate the theoretical value	59.62% (n = 31) endorse value guidance; 53.85% (n = 28) willing to engage with industrial contribution	Q12 and Q13

cific needs.

Pedagogical Diversification: From Lecture-Based to Interactive Learning

As reported in Section 5.2, a substantial proportion of students value academic discussion, yet the present lecture-centered format provides limited opportunities for sustained interaction. Interview comments suggest that spontaneous questioning often produces short exchanges rather than extended reasoning or collaborative problem solving. From a constructivist perspective, the main issue is not simply the amount of interaction, but how it is structured. Pre-class preparation can give students a common starting point, while guided discussion and case-based tasks can require them to articulate, challenge, and revise their understanding. This provides a clearer rationale for structured interaction than adding more questions to an otherwise unchanged lecture.

Educational reform also increasingly considers how professional courses communicate social and professional responsibility. Cheng (2022) argues that values education should be embedded in disciplinary learning rather than added as a separate message. Xu (2024) similarly describes interdisciplinary curriculum models that connect teaching resources with industry-defined roles and manufacturing processes. In the present course, this suggests that value-oriented content is most credible when it is attached to concrete engineering cases in which technical choices have industrial or social consequences.

The association reported in Section 5.2 also shows that students who considered academic discussion more helpful tended to report stronger recognition of value guidance. This relationship should not be read causally, but it suggests that interactive teaching and value-oriented content need not be treated as separate parts of the course. Cases involving high-performance alloys, aerospace forming, or lightweight manufacturing can provide a setting in which students discuss both technical decisions and their broader industrial significance.

Based on these findings, the proposed teaching design follows a simple sequence of pre-class preparation, in-class discussion, and post-class extension (see Table 9). Pre-class mind maps are intended to establish a shared knowledge structure; in-class group discussion gives students an opportunity to reason through course concepts; and post-class frontier lectures or industry-analysis tasks extend those concepts beyond the textbook. The preliminary implementation reported in Section 5.4 provides initial evidence that this sequence is feasible within the existing course structure, with 83.87% of post-implementation respondents reporting that group discussions deepened their understanding.

Assessment Redesign: From Single Summative to Optional Formative Model

As reported in Section 5.3, many students face unclear research methods and only a quarter perceive the assessment as improving their engineering practice ability. The existing course assessment, which relies on term papers, fails to evaluate essential student competences such as practical skills, problem-solving, and teamwork. In addition, the paper topics often do not align with core classroom concepts, including organizational evolution and plastic formation theories. This gap disrupts the link between learning and practical application, limiting the assessment's ability to measure genuine understanding. Furthermore, the grading criteria provide insufficient guidance for fostering innovation, as they lack explicit indicators for creativity.

The CIPP model (Context, Input, Process, Product) provides a useful way to interpret this weakness. A final paper mainly captures the product of learning and provides limited information about how students selected a topic, used evidence, applied theory, or responded

Table 10: Evaluation Method Reform Plan

Suggestions	Concrete Measure	Theoretical Foundation	Anticipated Goal	Support Rate	Source
Provide a database of cutting-edge technological hotspots	Guide students to independently select their research topics.	Theory of Self-Directed Learning (optional modules support personalized learning paths)	Enhancing the Cutting-Edge Nature of Thesis Topics	34.62% (n = 18) report lack of topic direction	Q9
Add a practical task section	Design Practice Assignment	Practice-Oriented Learning Theory (targeted practical assignments push learners to apply knowledge and tackle real-world engineering difficulties)	Attempt to solve practical engineering problems	Only 25.00% (n = 13) report engineering practice ability improvement from current assessment	Q3
Reporting during the setup phase	Conducting stages such as the project proposal and mid-term report	CIPP Evaluation Model (full-cycle evaluation covering background, input, process and product)	Optimizing Research Quality	32.69% (n = 17) want staged evaluation; 50.00% (n = 26) do not; optional design responds to both	Q8
Optimize the course paper	Define the Innovation Section	Value-Driven Leadership (clearcut innovation requirements guide students to take the initiative to explore new research perspectives and develop innovation-oriented thinking)	Cultivate innovative thinking	40.38% (n = 21) report insufficient innovation exploration	Q9

to feedback during the course. Formative elements such as proposal discussions, project drafts, peer review, or mid-term feedback can make those processes more visible and give instructors opportunities to intervene before the final submission. Puertas (2022) likewise reports that diversified assessment in engineering and related disciplines can better align evaluation with competency development. In the preliminary implementation, optional mid-term feedback sessions were introduced, and 67.74% of post-implementation respondents found them helpful for improving their course papers.

The data also argue against making every formative activity compulsory. Students reported different problems: 34.62% lacked direction in topic selection, 55.77% were uncertain about research methods, and 21.15% reported insufficient real-time teacher feedback; meanwhile, more than 70% of interviewees found mid-term questioning useful for identifying learning gaps. We therefore propose optional workshops on topic selection, methodology, and mid-term feedback, with participation linked to the relevant course task rather than added as a uniform requirement (Table 10). This design is intended to provide support where it is needed while avoiding unnecessary assessment load for students who do not require the same intervention.

Practical Implications and Systematic Extension

The preliminary implementation reported in Section 5.4 demonstrates that industry case lectures, enterprise field visits, and structured discussions can be integrated into a graduate engineering course without disrupting the existing credit structure, providing a practical reference for similar courses in the materials forming direction. The reform framework can next be extended to parallel courses, with further iterations informed by ongoing student feedback. Beyond course-level reforms, bridging the theory-practice gap also requires institutional support. Effective university-industry collaboration depends on clear frameworks for intellectual property sharing, personnel coordination, and resource co-construction, which are prerequisites for sustained field visits and enterprise project engagement. Future work should also broaden participation by engaging industry mentors and alumni employers as co-designers, so that curriculum decisions reflect the needs of all stakeholders.

Limitations

This study has several limitations.

(1) As an exploratory case study based on a single core course at one university, the generalizability of the findings is limited; the conclusions are more referential for similar materials forming programs than for engineering education as a whole.

(2) Although the diagnostic sample was expanded to 52 valid responses, it remains moderate in size, and the post-implementation survey involved only 21 students from a single cohort without a matched control group.

(3) Long-term effects on learning outcomes, such as thesis quality and subsequent research performance, have not yet been tracked.

Future research should extend the evaluation across multiple cohorts and parallel courses, include a control section, and incorporate input from enterprise supervisors and recent graduates to further validate whether the proposed reforms meet the needs of both learners and employers.

CONCLUSIONS

This study takes the course *Plastic Deformation of Metals and Alloys* as a case, which enrolls graduate students from Materials Science and Engineering, Materials and Chem-

ical Engineering, and Mechanical Engineering. Using a two-stage design, it first draws on 52 valid questionnaires and 16 semi-structured interviews across two cohorts to reveal deficiencies in course content, practical components, assessment methods and value orientation, and then reports post-implementation survey data from 31 students collected after a preliminary version of the reforms was implemented in the subsequent academic year.

The implemented measures included industry expert lectures covering high-temperature alloy forming, titanium alloy laser deposition, and spacecraft protective materials, a half-day enterprise field visit, structured group discussions focused on practical engineering challenges, and optional mid-term feedback sessions. Post-implementation survey data indicated that these measures strengthened students' perceived connection between course theory and industrial practice, with the proportion of students perceiving close content-practice alignment rising from 26.92% to 80.65%, although the case content remains concentrated on additive manufacturing and could be broadened to traditional forming processes such as stamping and forging in future iterations. A multidimensional evaluation system combining papers, practical tasks and optional workshops is proposed to provide a comprehensive assessment of student competence.

Through these targeted optimizations, the study provides an evidence-based diagnosis, a theory-driven reform design, and preliminary implementation feedback from one completed cycle. Long-term effects on learning outcomes, including thesis quality and subsequent research performance, remain to be tracked across multiple cohorts. The reform framework offers design propositions that other similar graduate engineering courses may adapt to their own disciplinary and institutional contexts.

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Ethics Approval and Consent to Participate
Not applicable.

Data Availability Statement
The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflict of Interest
The authors have no conflicts of interest to declare.

AI-Generated Content Declaration
During revision, OpenAI ChatGPT (GPT-5.6 Sol, accessed October 2026) was used solely to assist with English-language editing and preparation of responses to reviewer comments. It was not used to generate research data or conduct statistical analyses. All AI-assisted text was critically reviewed and revised by the authors, who take full responsibility for the final manuscript.

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