Outcome-Coupling and Process-Capability Evaluation of Blended Teaching Reform in Mechanics of Materials

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Abstract. Evaluation in "Mechanics of Materials" is traditionally limited to final exam scores, which often fails to capture a student's true engineering judgment or experimental skill. This study introduces a comprehensive evaluation framework at Kunming University, designed for a blended learning environment. By integrating digital resources, in-class derivations, and hands-on strain-gauge experiments, the course shifts from a single-point assessment to a process-oriented model. Data from two student cohorts show a marked improvement in performance: average scores rose from 66 to 77, and the pass rate surged to over 95%. Notably, the results indicate that calculation and experimental competencies are the most responsive to this new assessment style. These findings suggest that a data-informed, multi-dimensional approach more effectively mirrors student mastery and encourages deeper engagement in core engineering courses.

Keywords: Mechanics of Materials; Blended Teaching; Outcome-based Education; Process Capability; Engineering Education.

1 Introduction

As a cornerstone of mechanical engineering, Mechanics of Materials has evolved into a blended, "first-class" course [1, 2] requiring multi-dimensional evaluation beyond final scores. Addressing the lack of quantitative evidence in engineering education reform, this study treats the course as an engineering process. Using two years of official data, we analyze process exposure, grade distribution, and teaching stability to evaluate pedagogical effectiveness [3].

2 Course Context and Reform Scheme

The course is built around three outcomes [4]: mechanical modelling and basic stress–strain analysis, calculation and experiment-based understanding, and engineering judgement in terms of strength, stiffness, stability, economy, and safety. Its content covers basic deformations, stress analysis, strength theory, and column stability, with substantial time devoted to calculation and practice. A beam-bending strain-gauge experiment links theory with measured results. In the current reform, micro-videos, board

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derivation, case discussion, flipped tasks, chapter quizzes, and a beam-bending strain-gauge experiment with report were added, and the assessment structure was adjusted to 10% class performance, 15% homework, 10% quiz, 5% laboratory work, and 60% final examination (Fig. 1). This structure links the reform measures to CO1-CO3 through the coupling matrix in Table 1.

Table 1. Objective-assessment coupling structure derived from the syllabus.

Outcome	Weight	Class	HW	Quiz	Lab	Final	η_i	φ_i
CO1	28	5	5	0	0	18	0.357	0.643
CO2	38	5	5	5	5	18	0.526	0.474
CO3	34	0	5	5	0	24	0.294	0.706

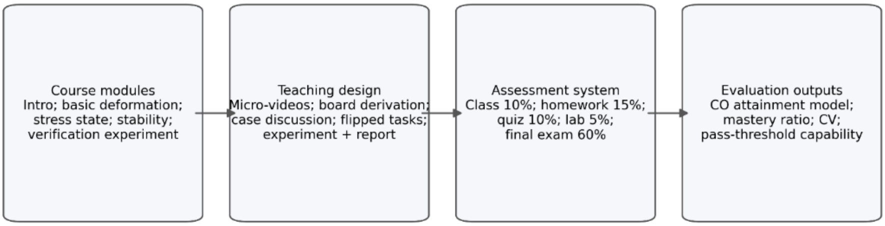

Fig. 1. Closed-loop framework for the blended reform of Mechanics of Materials.

3 Quantitative Evaluation Model

3.1 Objective-Assessment Coupling Matrix

Let the course contain three outcomes and five assessment components: class performance, homework, chapter quiz, laboratory work, and final examination. According to the syllabus, the allocated points that support each course outcome can be written as a coupling matrix (Fig. 2)

$$W = [B_{ij}]_{3\times 5} \tag{1}$$

where B_{ij} denotes the points contributed by assessment component j to course outcome i, and the row sum $A_i = \sum_j B_{ij}$ is the total weight of course outcome i in the whole course. For the present course, $A_1 = 28$, $A_2 = 38$, and $A_3 = 34$.

If $\overline{s}_{ij}$ is the average score actually obtained by the class in component j for course outcome i, then the direct attainment of the i-th outcome can be expressed as

$$G_i = \sum_{j=1}^{5} \left(\frac{B_{ij}}{A_i} \right) \left(\frac{\bar{s}_{ij}}{B_{ij}} \right), \quad i = 1, 2, 3 \tag{2}$$

and the total course attainment is

$$H = \sum_{i=1}^{3} \left(\frac{A_i}{100} \right) G_i \tag{3}$$

Equations (2)–(3) operationalize the syllabus-defined point allocation into outcome attainment [5], so the scoring logic of the framework is fully determined by the official assessment scheme rather than by additional subjective weighting.

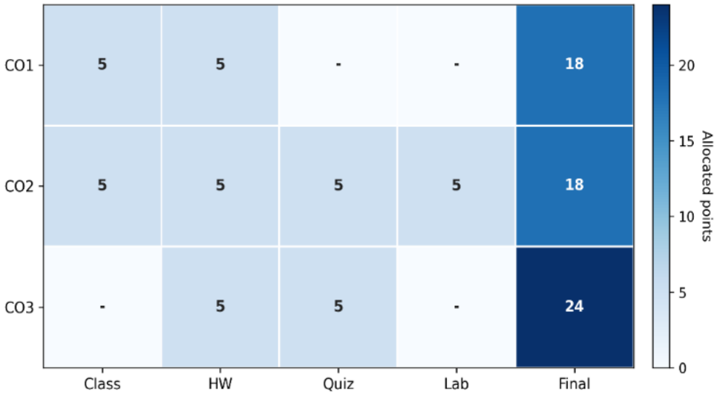

Fig. 2. Heatmap of the objective-assessment coupling matrix.

3.2 Process Sensitivity and Final Dependence

To interpret the structure of blended reform, the process sensitivity coefficient of each outcome is defined as

$$\eta_i = \frac{B_{i1} + B_{i2} + B_{i3} + B_{i4}}{A_i} \tag{4}$$

while the final dependence is

$$\phi_i = \frac{B_{i5}}{A_i} = 1 - \eta_i \tag{5}$$

A larger η_i means that a larger share of an outcome is assessed through class performance, homework, quizzes, and laboratory work, whereas a larger ϕ_i means stronger dependence on the final examination. In this study, η_i is interpreted as process exposure rather than a direct responsiveness measure.

3.3 Semester-Level Quality Indicators

The official semester score sheets provide the total average score \mu, standard deviation σ, pass rate P, excellent rate E, and grade counts in each score band. Based on these data, two additional indicators are used. The first is the mastery ratio

$$M = \frac{n_{70-100}}{N} \tag{6}$$

which reflects the share of students reaching at least the "medium" level. The second is the coefficient of variation

$$CV = \frac{\sigma}{\mu} \tag{7}$$

To introduce an engineering interpretation of teaching quality, the passing line of 60 is treated as a lower specification limit. A pass-threshold capability index is then defined as

$$Cpl = \frac{\mu - 60}{3\sigma} \tag{8}$$

A larger Cpl indicates a larger safety margin between the score distribution and the pass threshold. This index does not assume that student learning is identical to industrial manufacturing; rather, it offers a compact risk-oriented description of how far the observed score distribution stands above the minimum acceptable level.

3.4 Statistical Test

To test whether the two cohorts share the same grade-distribution pattern, a chi-square test is performed using the five grade bands (90–100, 80–89, 70–79, 60–69, and <60). Cramer's V is reported as an effect-size indicator.

4 Results and Discussion

Table 1 shows that CO2 has the highest process sensitivity ($\eta_2 = 0.526$) and the lowest final dependence ($\varphi_2 = 0.474$), whereas CO3 has the lowest process sensitivity ($\eta_3 = 0.294$) and the highest final dependence ($\varphi_3 = 0.706$). This pattern indicates that CO2 is the outcome most directly exposed to blended-process activities under the current assessment design.

Both cohorts included 65 students. From 2022–2023 to 2023–2024, the mean score increased from 66.37 ± 14.83 to 77.46 ± 12.36 (Welch's $t = 4.63$, $p < 0.001$, $d = 0.81$), while pass, mastery, and excellence rates also increased and the failure rate fell from 26.15% to 4.62% (Table 2, Fig. 3).

Table 2. Semester-level statistics and derived engineering indicators

Year	N	Mean	Std.	Pass %	Excellent %	Mastery %	Fail %	CV	Cpl
2022–2023	65	66.37	14.83	73.85	0.00	52.31	26.15	0.223	0.143
2023–2024	65	77.46	12.36	95.38	18.46	75.38	4.62	0.160	0.471

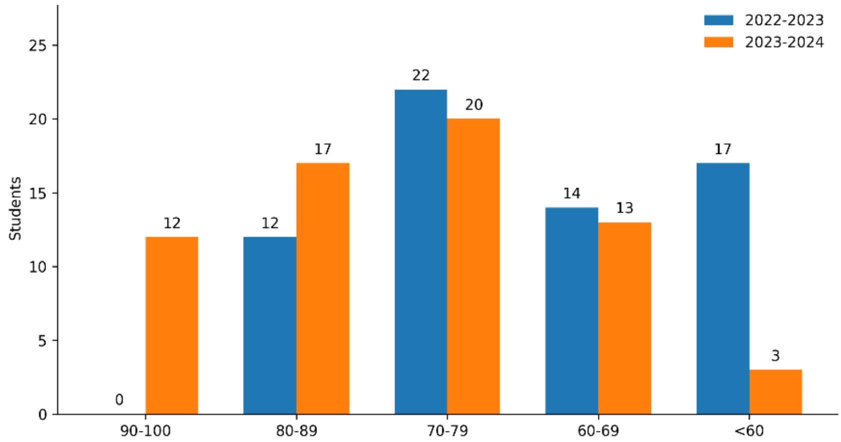

Fig. 3. Grade-distribution shift between the two academic years.

The five-band grade distributions differed significantly between cohorts ($\chi^2 = 22.79$, $p < 0.001$, Cramer's V = 0.419). The later cohort also showed a larger pass-threshold capability (Cpl = 0.471 vs. 0.143) and lower dispersion (CV = 0.160 vs. 0.223) (Fig. 4), although the analysis is still limited to summary-level data from two cohorts at one university.

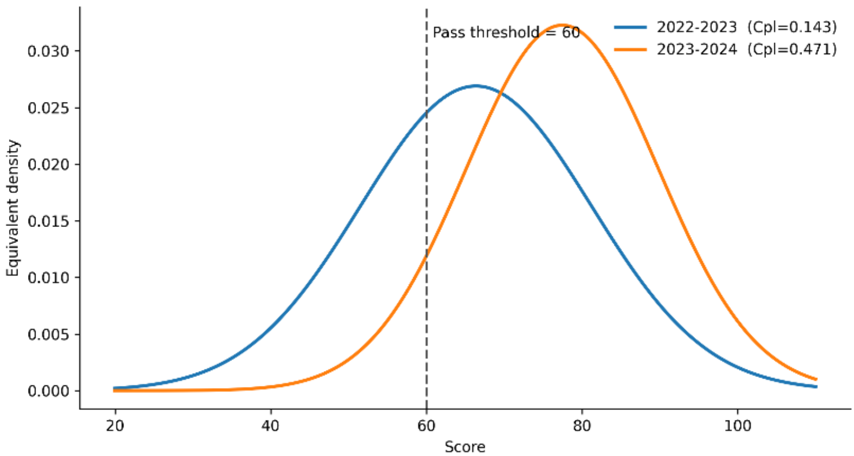

Fig. 4. Pass-threshold capability illustrated by mean-std equivalent score distributions.

5 Conclusions

This study developed a syllabus-aligned quantitative framework for evaluating blended teaching reform in Mechanics of Materials, combining an objective-assessment coupling matrix with mastery ratio, coefficient of variation, and pass-threshold capability. Using two academic years of official course data, the study showed that CO2 had the highest process exposure under the current assessment design, but direct responsiveness was not separately measured at the outcome level. After the reform, pass, mastery, and excellence rates all increased, while the lower-score group became much smaller. Score variation also decreased, suggesting a more stable teaching effect. The framework offers a practical way to analyse engineering-course reform with quantitative indicators, but its wider applicability should be tested with larger samples, multi-institutional data, and, where available, student-level covariates.

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