ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26oct1421

Integrating Research and Project-Based Learning: A Competency-Oriented Teaching Reform for the Civil Engineering Materials Course

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Publication Date: 2026/10/31

Abstract: Given the broad scope of the Civil Engineering Materials course, the close relationship between material properties and engineering applications, and the constraints imposed by curing ages on cementbased materials testing, this study develops a research-integrated and project-based teaching reform framework through literature analysis and curriculum design, drawing on the theories of constructive alignment, project-based learning, and research-based learning. Representative research cases are selected and adapted into undergraduate projects with clearly defined variables, experimental tasks, and expected deliverables. Taking low-carbon cement mortar mix design as an example, an eight-week instructional module is designed to encompass research question formulation, mix design, specimen preparation, performance testing, and multi-criteria engineering evaluation. Five competency dimensions are identified, including application of materials knowledge, experimental design, data analysis and interpretation, sustainable engineering decision-making, and engineering communication. Alignment is established among project-level competency objectives, learning activities, and assessment evidence, supported by an analytic scoring rubric and mechanisms for process-based assessment and feedback. The proposed framework emphasizes the integration of research questions into course activities, coordination between experimental curing periods and instructional schedules, and evidence-based assessment of student competencies, providing a reference for curriculum reform in civil engineering materials and related courses.

Keywords: *Civil Engineering Materials; Teaching Reform; Integration of Research and Teaching; Project-Based Learning; Outcome-Based Education.*

How to Cite: Jin Li; Peiyuan Chen; Jinjin Ge (2026) Integrating Research and Project-Based Learning: A Competency-Oriented Teaching Reform for the Civil Engineering Materials Course. *International Journal of Innovative Science and Research Technology*, 11(10), 2430-2437. https://doi.org/10.38124/ijisrt/26oct1421

I. INTRODUCTION

Civil Engineering Materials is a fundamental course in civil engineering education that bridges materials science with structural design, construction technology, and engineering quality control. It covers the composition, structure, properties, and applications of engineering materials. With the transition of the civil engineering industry toward low-carbon and sustainable development, engineering professionals are expected not only to understand the fundamental properties and performance characteristics of materials but also to possess competencies in material selection, experimental design, data analysis, and engineering decision-making. These competencies enable them to evaluate material alternatives under multiple constraints, including safety, economic, and environmental considerations. International engineering accreditation criteria also emphasize engineering experimentation, data analysis, and comprehensive judgment in addressing complex engineering problems [1]. However, the course encompasses a broad range of knowledge, and material properties are influenced by numerous factors. In particular, experiments on cement-based materials are constrained by preparation procedures, curing conditions, and testing ages, posing challenges to the integration of theoretical and practical instruction, experimental organization, and competency assessment. Therefore, developing a curriculum that emphasizes engineering competency development is of considerable importance.

Various teaching reforms have been investigated in civil engineering and related disciplines. Li et al. [2]

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26oct1421

introduced the Conceive-Design-Implement-Operate (CDIO) approach into the Civil Engineering Materials course, aiming to develop students' engineering practical skills through curriculum restructuring and team-based design tasks. Xu et al. [3] proposed a project-based approach to reform practical teaching, while Bartels and Stolz [4] explored the integration of project-based learning and research-based learning in civil engineering education. Oller et al. [5] implemented project-based learning through authentic engineering projects in a reinforced concrete course and evaluated its effectiveness. These studies provide valuable insights into integrating research activities and project-based learning into professional courses. Nevertheless, differences in knowledge structures, experimental conditions, and educational objectives across courses limit the direct transferability of existing approaches. Therefore, further exploration is needed to develop approaches tailored to Civil Engineering Materials, particularly in transforming research content into teaching activities, coordinating experimental schedules with course delivery, and assessing student competencies.

Teaching assessment plays an essential role in evaluating the achievement of course learning outcomes and supporting continuous improvement. Guo et al. [6] noted that studies on project-based learning have frequently relied on questionnaires and interviews to evaluate learning effectiveness, while direct assessment of students' learning processes and final products requires further attention. Ramírez de Dampierre et al. [7] emphasized the importance of establishing appropriate assessment and feedback mechanisms in project-based learning and CDIO-based educational reforms. In Civil Engineering Materials education, students' competencies should be demonstrated not only through their mastery of theoretical knowledge but also through tangible learning outcomes, including experimental design, data analysis, interpretation of material properties, and evaluation of engineering alternatives. Accordingly, an assessment framework that aligns learning objectives, teaching activities, student learning outcomes, and assessment feedback is needed.

Considering the knowledge structure, experimental characteristics, and engineering competency requirements of the course, this study combines literature analysis with curriculum design to develop a research-integrated and project-based teaching reform framework. The framework addresses three key aspects: transforming research questions into undergraduate learning tasks, coordinating material curing periods with instructional schedules, and assessing students' comprehensive competencies through evidence derived from their work.

II. DESIGN RATIONALE AND OVERALL APPROACH TO TEACHING REFORM

- *Course Characteristics and Requirements for Teaching Reform*

The Civil Engineering Materials course covers material composition, fundamental properties, testing methods, and engineering applications, with close interconnections among its topics. Course instruction should integrate material microstructure, mix design, and macroscopic properties to develop students' ability to comprehensively apply disciplinary knowledge to the analysis of engineering materials problems. Experiments involving cement-based materials encompass raw material testing, mix design, specimen preparation, curing, and performance testing, forming a closely connected sequence of activities. In particular, mechanical property testing is constrained by curing ages and is difficult to complete within a single laboratory session. Therefore, laboratory instruction should emphasize experimental design, process documentation, data analysis, and interpretation of results while ensuring standardized experimental procedures, thereby developing students' ability to analyze experimental errors and solve problems related to material properties. Green and low-carbon development has provided new research cases for course instruction, including the resource utilization of industrial solid waste, low-clinker cementitious materials, and low-carbon concrete. Engineering applications of these materials require comprehensive consideration of mechanical properties, durability, resource consumption, environmental impacts, and economic costs. Therefore, sustainable engineering principles should be integrated into course instruction to develop students' ability to select materials and make engineering decisions under multiple objectives and constraints.

Based on these characteristics, teaching reform should focus on strengthening the connection between theory and engineering practice, enhancing experimental inquiry and data analysis, and integrating material performance evaluation with engineering application conditions, thereby promoting the coordinated development of students' competencies in applying disciplinary knowledge, conducting experimental investigations, and making comprehensive engineering decisions.

- *Theoretical Foundations and Design Principles of Teaching Reform*

Constructive alignment theory emphasizes the alignment of learning objectives, teaching activities, and assessment tasks. Biggs [8] pointed out that teaching activities and assessment methods should be selected according to the intended learning outcomes. Accordingly, in addition to ensuring the acquisition of fundamental knowledge, the Civil Engineering Materials course should establish clear competency objectives in experimental design, data analysis, interpretation of material properties, and evaluation of material alternatives, together with corresponding teaching activities and assessment criteria.

Project-based learning uses authentic engineering tasks as a basis for engaging students in problem analysis, solution design, experimental verification, and communication of results, whereas research-based learning emphasizes hypothesis formulation, variable control, and evidence interpretation. By simplifying research variables and reducing task complexity, research questions can be transformed into instructional projects appropriate for the cognitive levels of undergraduate students, allowing project

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26oct1421

tasks to serve as a vehicle for research inquiry and the application of disciplinary knowledge.

Based on these theoretical foundations, this study follows the principles of goal orientation, task suitability, and evidence-based assessment. Drawing on engineering education theories, relevant literature on teaching reform, and the experimental characteristics of cement-based materials, the design process sequentially involves analyzing competency requirements, mapping research cases to course topics, designing project tasks, and identifying assessment evidence. Students' competency performance is assessed through learning products such as experimental plans, process records, and analytical reports. Meanwhile, course hours, experimental equipment, material curing periods, and teaching conditions are coordinated to ensure adequate coverage of foundational course content, the feasibility of the proposed design, and the traceability of assessment. In addition, literature analysis is primarily used to establish the rationale for the instructional design.

- *Overall Framework for Research-Integrated and Project-Based Teaching Reform*

Based on an analysis of the course's teaching requirements and relevant educational theories, this study develops an overall framework for teaching reform that is guided by competency development objectives, driven by research questions, organized around project tasks, centered on experimental inquiry as the primary practical activity, and supported by learning outcome assessment as the basis for feedback, as shown in Fig. 1. The framework takes the integration of research content with the course knowledge system as its starting point. Through project-based teaching, students are engaged in analyzing materialsrelated problems and conducting experimental investigations, while competency assessment is incorporated throughout the instructional design process, establishing a course teaching system in which teaching objectives, teaching activities, learning outcomes, and assessment feedback are aligned, as presented in Table 1. Instructors select representative research questions based on course content and transform the key variables and feasible experiments into instructional tasks. Students produce learning outcomes such as experimental plans, original experimental records, data analyses, and engineering evaluations. Instructors conduct process-based assessment and provide feedback using corresponding scoring rubrics, thereby achieving effective alignment among course objectives, teaching activities, learning outcomes, and competency assessment.

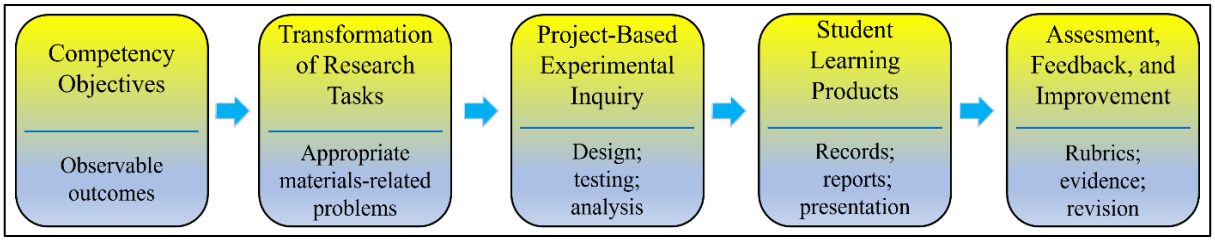


Fig 1 Framework for Curriculum Teaching Reform Integrating Research and Project-Based Learning.

Table 1 Alignment Among Course Competency Development Objectives, Teaching Activities, and Assessment Evidence.

Competency Development Objectives	Main Teaching Activities	Learning Products and Assessment Evidence to Be Collected
Application of Materials Knowledge	Material performance analysis; discussions of research cases; analysis of engineering problems	Rationale for material selection; material performance analysis reports
Experimental Design	Development of experimental plans; selection of experimental parameters; design of control groups	Experimental design documents; descriptions of variables and experimental conditions
Data Analysis and Interpretation	Experimental data organization; performance comparisons; error analysis	Original experimental records; analytical figures and tables; results discussion reports
Sustainable Engineering Decision-Making	Comprehensive comparison of material performance, costs, and environmental impacts	Material alternative evaluation reports; rationale for decision-making
Engineering Communication	Group collaboration; project presentations; oral defense of project outcomes	Project reports; presentation materials; records of individual contributions

III. DESIGN OF RESEARCH-INTEGRATED AND PROJECT-BASED TEACHING REFORM

- *Restructuring Course Content Through Research Integration*

The restructuring of course content should be based on the course syllabus and program requirements. While maintaining the integrity of the fundamental knowledge system, knowledge of material composition and structure, properties, preparation, and engineering applications should be integrated with representative research cases. Taking cement-based materials as an example, research questions concerning the effects of supplementary cementitious materials on workability and mechanical properties, as well as the deterioration of material properties under different environmental conditions, can be introduced to guide

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26oct1421

students in analyzing the relationships between material composition, mix proportions, curing conditions, service environments, and material properties. The selection of research cases should consider disciplinary relevance, instructional representativeness, task suitability, and experimental feasibility. For topics involving complex microstructural characterization or long-term durability studies, teaching can be conducted through literature analysis, discussions of research methods, and interpretation of authentic research data, whereas student experiments should primarily focus on conventional material preparation, workability testing, and mechanical property testing. By simplifying research variables and experimental tasks, research content can be adapted to undergraduate course hours and experimental conditions while preserving the fundamental process of scientific inquiry. The specific correspondence between the transformation of research content and course teaching content is presented in Table 2.

Table 2 Instructional Design for Integrating Research Content into the Civil Engineering Materials Course.

Course content	**Research questions to be integrated**	**Teaching task design**	**Primary Competency Development Objectives**
Cement and cementitious materials	Effects of supplementary cementitious materials on the properties of cement-based materials	Analyze the relationship between cementitious material composition and changes in material properties	Application of materials knowledge; performance analysis
Mortar and Concrete Mix Design	Effects of material composition and mix design parameters on workability and mechanical properties	Design comparative experiments and analyze the relationship between mix proportions and material properties	Experimental design; data interpretation
Concrete Durability	Effects of material composition and environmental factors on durability	Compare durability assessment methods and existing research data for different material systems	Comprehensive analysis; engineering judgment
Green Building Materials	Resource utilization of industrial by-products and development of low-carbon cementitious materials	Compare the technical performance, resource utilization, and environmental impacts of materials	Sustainability trade-offs; engineering decision-making

➢ *Project-Based Teaching Design Through the Transformation of Research Questions*

Taking “Low-Carbon Cement Mortar Mix Design” as an example, the composition of cementitious materials, workability, mechanical properties, and sustainable engineering evaluation are integrated into a comprehensive teaching task. Teaching activities are organized into four stages: introduction of the research question, experimental design, experimental implementation, and comprehensive evaluation.

- Introduction of the research question and definition of project tasks. Drawing on research findings on low-carbon cementitious materials, instructors introduce the application background and engineering constraints of supplementary cementitious materials and pose the research question: "How can cement consumption be reduced while meeting the basic performance requirements of mortar?" Through literature review and group discussions, students analyze the properties of supplementary cementitious materials and their influencing factors, identify research variables, evaluation indicators, and technical constraints, formulate preliminary research hypotheses, and distinguish between questions that can be experimentally verified and environmental impact issues that require literature-based analysis.
- Mix design and development of experimental plans. Taking ground granulated blast-furnace slag (GGBFS) as an example, three experimental groups with cement replacement levels of 0%, 15%, and 30% are proposed. The effects of replacement level on mortar properties are investigated while maintaining constant total binder mass, sand-to-binder ratio, water-to-binder ratio, and curing conditions. The specific replacement levels are determined according to material characteristics, preliminary experimental results, and teaching conditions, without assuming an optimal replacement level in advance. Students specify the experimental variables, control conditions, number of specimens, testing ages, and data recording requirements, and implement their experimental plans after instructor review.
- Experimental implementation and analysis of material properties. Following their experimental plans, students carry out material weighing, mortar mixing, workability testing, specimen preparation and curing, and mechanical property testing at specified ages. By systematically documenting experimental conditions and raw data, students assess data reliability and explain differences in material properties through replicate testing and error analysis. For results that deviate from the initial hypotheses, particular attention is given to possible causes related to material characteristics, variable control, and experimental errors.
- Comprehensive evaluation and presentation of project outcomes. Based on experimental results, students compare the technical performance of different mortar mixes and evaluate their economic performance and carbon emissions using material consumption, price information, and environmental data, while specifying data sources, assessment boundaries, and underlying assumptions. Where complete lifecycle data are

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26oct1421

unavailable, carbon emissions may be estimated for the material production stage within a defined system boundary, without directly equating cement replacement levels with reductions in life-cycle carbon emissions. Finally, students prepare project reports containing research hypotheses, experimental plans, raw data, result analyses, and justifications for material selection. Through presentations and discussions of project outcomes, students evaluate the rationality and limitations of their proposed solutions.

- *Organization and Implementation of Laboratory Teaching Guided by Research Inquiry*

Experiments involving cement-based materials encompass specimen preparation, curing, and performance testing at different ages, forming a continuous sequence of activities. To coordinate experimental durations with course hours, a staged teaching approach integrating in-class and out-of-class activities is adopted. The "Low-Carbon Cement Mortar Mix Design" project is organized into an eight-week instructional module, incorporating project discussions, experimental design, experimental implementation, data analysis, and presentation of project outcomes. The detailed schedule is presented in Table 3.

Laboratory teaching combines group collaboration with individual tasks. Each group conducts material preparation and performance testing under consistent experimental requirements and variable control conditions, followed by comprehensive analysis through data sharing. Instructors specify requirements for laboratory safety, standardized experimental procedures, and data recording, and guide students in documenting material sources, mix proportions, preparation and curing conditions, and testing times to ensure data traceability. Meanwhile, experimental replicates are appropriately arranged, with a distinction made between independent experimental replicates and repeated measurements on specimens from the same batch to improve the reliability of data analysis. Mortar strength and fluidity tests are conducted with reference to GB/T 17671-2021 [9] and GB/T 2419-2005 [10], respectively. The applicability and limitations of these standard methods to modified mortar testing are clarified to avoid directly equating the resulting measurements with those obtained from standard testing of cement products. Environmental impact assessment may refer to ISO 14040 [11], with simplified analyses conducted based on clearly defined data sources and assessment boundaries, without treating them as equivalent to a complete life cycle assessment. To address the intervals in teaching activities resulting from curing age requirements, experimental tasks are arranged in advance, and theoretical instruction and practical activities are scheduled alternately. Literature reading, mix proportion verification, collection of cost and environmental data, and interim analyses are incorporated into the curing periods. For tests at later ages that cannot be completed within the course period, existing data from reliable sources with clearly documented experimental conditions may be used to support the analysis, while distinguishing between outcomes from students' own experiments and analyses based on external data. By coordinating laboratory activities with project tasks, a continuous inquiry process is established, providing a basis for assessing students' competencies in experimental design, data analysis, and engineering judgment.

Table 3 Eight-Week Implementation Plan for Project-Based Teaching of Low-Carbon Cement Mortar

Teaching Stage	Schedule	Main Teaching Content and Tasks	Learning Outcomes at Each Stage
Project Introduction	Week 1	Introduce the research background, clarify project objectives, and conduct literature review and problem analysis	Project task analysis and research hypotheses
Experimental Design and Specimen Preparation	Week 2	Develop and review mix proportions and experimental plans; complete material mixing, workability testing, and specimen casting	Experimental design documents and original experimental records
Early-Age Performance Testing	Week 3	Test specimens that have reached 7 days of age and analyze preliminary results	Early-age performance data and analysis records
Interim Discussion	Week 4	Discuss factors influencing material properties, experimental errors, and research hypotheses, and compare findings with the literature	Interim analysis report
Engineering Constraints Analysis	Week 5	Collect material price and environmental data, and define the boundaries and evaluation indicators for carbon emission estimation	Engineering evaluation plan
Later-Age Performance Testing	Week 6	Test specimens that have reached 28 days of age and organize experimental data	Complete testing data at the specified ages
Comprehensive Analysis	Week 7	Compare material properties, conduct cost analysis, and perform a preliminary environmental impact assessment	Comprehensive project evaluation report
Presentation and Discussion of Project Outcomes	Week 8	Conduct project presentations, oral defenses, peer feedback, and individual reflection	Project reports, presentation materials, and reflection records

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26oct1421

- Note: The above schedule represents a proposed instructional design. The actual specimen preparation date in Week 2 serves as the starting point, and testing at 7 and 28 days must be scheduled according to the actual ages of the specimens. Testing in Weeks 3 and 6 is subject to the corresponding age requirements being met. The specific implementation schedule should be adjusted according to course hours and the teaching timetable.

➢ *Coordinated Teaching Mechanism for Research Integration and Project-Based Learning*

The key to coordinating research integration with project-based teaching lies in effectively aligning research content, project tasks, teaching activities, and competency objectives. Based on course objectives and students' prior knowledge, instructors select research questions of instructional value and identify their key variables, experimental methods, and engineering constraints. By simplifying tasks and specifying limiting conditions, these research questions are transformed into instructional projects suitable for undergraduate students, allowing research questions to serve as the driving force behind project-based learning.

Project implementation should be coordinated with the progression of theoretical instruction, incorporating knowledge of material composition, factors influencing material properties, mix design, and testing methods into different project stages. Through theoretical guidance, methodological demonstrations, and discussions at different stages, instructors guide students in developing experimental plans, conducting experiments to test their hypotheses, and analyzing results. They also provide feedback based on learning products, including research hypotheses, experimental design documents, original experimental records, and analytical reports, helping students refine their experimental plans and interpretations of results and achieve effective alignment among knowledge acquisition, experimental inquiry, and competency assessment.

Coordinated teaching should also take into account course hours, experimental conditions, and the extent of student participation. Project scope and task difficulty should be appropriately controlled to avoid excessive reliance on sophisticated experimental equipment, while clearly defined group roles and individual responsibilities should ensure opportunities for student participation. By integrating guidance through research questions, implementation of project tasks, and feedback on learning products, a coordinated teaching mechanism suited to regular course instruction can be established, providing a basis for subsequent competency assessment and continuous improvement in teaching.

IV. COURSE ASSESSMENT SYSTEM AND CONTINUOUS IMPROVEMENT MECHANISM

➢ *Course Assessment Objectives for Comprehensive Competency Development*

Course assessment should be aligned with teaching objectives and the project implementation process, emphasizing a comprehensive evaluation of students' competencies in knowledge application, experimental inquiry, and engineering practice while assessing their fundamental knowledge of materials. Based on constructive alignment theory [8] and considering the characteristics of the Civil Engineering Materials course and its project-based teaching tasks, a competency assessment framework is developed across five dimensions: application of materials knowledge, experimental design, data analysis and interpretation, sustainable engineering decision-making, and engineering communication. Specifically, the application of materials knowledge focuses on analyzing the relationships among material composition, structure, and properties; experimental design emphasizes the selection of experimental variables, establishment of control groups, and development of experimental plans; data analysis and interpretation focus on data processing, error analysis, and assessment of result reliability; sustainable engineering decision-making emphasizes the comprehensive consideration of material performance, economic costs, and environmental impacts; and engineering communication focuses on technical reporting, teamwork, and project presentations and defenses. Experimental design documents, original experimental records, performance analysis reports, and project evaluation reports are used as direct assessment evidence. These are combined with theoretical knowledge assessments to evaluate both students' knowledge acquisition and comprehensive competency performance.

➢ *Multidimensional Assessment Criteria and Scoring Rubrics Based on Learning Outcomes*

To improve the relevance and practicality of course assessment, an analytic scoring rubric is adopted to evaluate students' project learning outcomes across five dimensions: application of materials knowledge, experimental design, data analysis and interpretation, sustainable engineering decision-making, and engineering communication [12]. Four performance levels (Excellent, Good, Basic Achievement, and Needs Improvement) are established for each dimension. Scores are assigned based on the completeness, conformity with specified requirements, and quality of argumentation demonstrated in students' learning outcomes. The specific assessment criteria are presented in Table 4. Project assessment considers both team outcomes and individual performance. Group experimental reports and project presentations are primarily used to evaluate the quality of team task completion, whereas competencies in experimental design, data interpretation, and engineering judgment are assessed through individual tasks, independent analyses, and oral defenses, thereby avoiding the substitution of group scores for assessments of individual student competencies.

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Table 4 Comprehensive Competency Assessment Criteria and Analytic Scoring Rubric

Assessment Dimension	Excellent (4 Points)	Good (3 Points)	Basic Achievement (2 Points)	Needs Improvement (1 Point)
Application of Materials Knowledge	Accurately applies relevant theories to explain differences in material properties, with comprehensive analysis	Correctly applies major theories to explain changes in material properties, with generally reasonable analysis.	Identifies the main influencing factors, but provides insufficient theoretical explanations.	Demonstrates insufficient understanding of key concepts and has difficulty reasonably
	and sufficient supporting evidence.			explaining material properties.
Experimental Design	Appropriately selects variables and establishes controls, follows standardized experimental methods, and develops a complete and feasible experimental plan.	Develops a generally reasonable experimental plan that meets the main research requirements.	Develops a largely complete experimental design, but with deficiencies in variable control or implementation details.	Selects research variables and experimental methods inappropriately, resulting in a plan that is difficult to implement.
Data Analysis and Interpretation	Maintains complete experimental records, processes data according to established procedures, and analyzes differences in material properties, experimental errors, and the scope of applicability of conclusions.	Processes data correctly and provides reasonable interpretations of the main experimental results.	Completes basic data organization, but provides relatively superficial analysis of the results.	Makes significant errors in data processing and fails to provide effective interpretations of the results.
Sustainable Engineering Decision-Making	Conducts comprehensive comparisons based on performance requirements, costs, and environmental data, with clearly defined assessment boundaries and well-supported conclusions.	Considers major engineering constraints and makes generally reasonable comparisons among alternatives.	Identifies some constraints, but provides insufficient comprehensive evaluation.	Lacks necessary analysis of engineering constraints and provides insufficient justification for selecting an alternative.
Engineering Communication	Presents a well-structured report with properly formatted figures and tables, complete arguments, and accurate responses to key questions.	Communicates relatively clearly, with generally reasonable presentations of outcomes and responses to questions.	Completes basic presentations, but demonstrates weaknesses in argumentation logic or adherence to presentation standards.	Produces an incomplete report and has difficulty clearly explaining the research process and conclusions.

- *Process-Based Assessment and Feedback on Learning Outcomes*

Process-based assessment is conducted throughout project implementation, focusing on problem analysis, experimental design, variable control, data recording, and interpretation of results. Project reports, oral presentations or defenses, and individual reflections are also assessed. Instructors provide timely feedback based on the results of assessments at different stages, guiding students in refining their experimental plans and research conclusions. To improve the objectivity and consistency of assessment, assessment criteria, expected deliverables, and scoring standards should be clearly defined before the project begins. For assessment dimensions such as experimental design, data interpretation, and engineering decision-making, independent scoring by two assessors may be combined with discussions to resolve scoring discrepancies. In addition, expert review, pilot scoring, and inter-rater agreement analysis can be employed to refine the scoring rubric and improve the reliability of assessment results.

- *Utilization of Assessment Results and Continuous Improvement of Teaching*

Course assessment follows a continuous improvement process of "objectives–evidence–feedback– revision". Based on scores across the five competency dimensions, representative learning outcomes, and commonly identified problems, instructors identify weaknesses in teaching. In response to deficiencies in experimental design, data analysis, and engineering decision-making, targeted training in variable control, error analysis, and the evaluation of material costs and environmental impacts is strengthened. Teaching adjustments and their supporting rationale are also documented to establish a traceable continuous improvement mechanism. Course quality evaluation should integrate direct evidence, such as student work and project oral defenses, with indirect feedback, such as students' perceptions of their

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26oct1421

learning, while distinguishing actual competency performance from subjective learning experiences. The attainment of learning objectives for the entire course should be analyzed in accordance with the course syllabus by considering assessment results from theoretical examinations, conventional laboratory experiments, and project assessments, rather than relying solely on project scores to evaluate the attainment of course learning objectives.

V. CONCLUSIONS

Based on the characteristics of the Civil Engineering Materials course and drawing on the theories of constructive alignment, project-based learning, and research-based learning, this study proposes a teaching reform framework integrating research activities with project-based teaching. The main conclusions are as follows:

- A research-integrated and project-based teaching reform framework is developed. Through the selection of research cases, identification of research questions, and transformation of research content into instructional tasks, problem analysis, experimental design, and interpretation of results are incorporated into course instruction, promoting effective alignment among research content, project tasks, and competency development objectives.
- Taking low-carbon cement mortar mix design as an example, a comprehensive teaching task is designed to encompass material selection, mix design, performance testing, data analysis, and engineering evaluation. Considering the curing age requirements of cement-based materials, a staged teaching implementation plan integrating in-class and out-of-class activities is proposed, providing a specific approach to incorporating research inquiry into conventional laboratory teaching.
- A multidimensional assessment framework based on learning processes and project outcomes is developed across five competency dimensions: application of materials knowledge, experimental design, data analysis and interpretation, sustainable engineering decision-making, and engineering communication. Assessment criteria, learning evidence, and feedback mechanisms are specified to provide a basis for analyzing the attainment of course learning objectives and supporting continuous improvement in teaching.

Overall, this study develops a curriculum reform framework that is oriented toward competency development, organized around project tasks, and grounded in learning outcomes as assessment evidence. The proposed framework may serve as a reference for teaching reform in Civil Engineering Materials and related courses.

ACKNOWLEDGEMENTS

This study was funded by the Anhui Provincial New Era Education Quality Project (Graduate Education) (2024jyjxggyjY188), and the General Project of the Anhui Provincial Graduate Education Quality Enhancement Program (No. 2023jyjxggyjY123).

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