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AI-Assisted Structural Testing Education: Test Design and Evidence-Based Interpretation

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Abstract: *This paper proposes an artificial intelligence (AI)-assisted redesign of the Civil Engineering Structural Testing Technology course, with the development of disciplinary judgment as its central objective. The redesign addresses three problems: difficulty applying knowledge learned in separate chapters to specific test decisions, insufficient verification of parameter choices and loading arrangements in student-designed test plans, and a lack of observational evidence to support the interpretation of measured data. In theoretical instruction, knowledge and reference materials are organized around relationships among test decisions; AI assists with organization and retrieval, while instructors and students jointly check the applicability of relevant standard provisions. The open-topic design assignment follows an iterative sequence of initial drafting, AI questioning, student verification, and instructor review, introducing verification before implementation. Laboratory preparation, discussion, and reporting are organized around observational evidence so that interpretations can be traced to original records. Two cases are presented: the design of a shear test for a simply supported concrete beam and an investigation of the static and dynamic characteristics of a uniform-strength cantilever steel beam. The cases examine material parameter selection and the conditions for uniform strength, respectively, and specify AI-assisted tasks, student verification methods, and assessment criteria. The course uses general-purpose large language models accessible to students and requires no dedicated platform or additional hardware investment. Its educational effectiveness remains to be examined using evidence from implementation.*

Keywords: *Structural testing technology; AI-assisted teaching; Test plan design; Experimental data analysis; Teaching reform.*

I. INTRODUCTION

Civil Engineering Structural Testing Technology is a core course in the civil engineering curriculum that combines theory and practice. Structural testing provides a fundamental means of understanding structural behavior under load, examining analytical assumptions, and evaluating structural performance. The course therefore requires students not only to master loading, measurement, and data processing methods but also to select methods and interpret phenomena in relation to test objectives. Students must explain not only how to conduct a test but also why particular specimens, loading protocols, and measurement layouts are appropriate, and what conclusions the observations can support. The course contributes to three graduation requirement indicators: scientific design of experimental plans, data processing and analysis leading to conclusions, and teamwork. Progressing from mastery of methods to evidence-based engineering judgment gives these indicators concrete meaning in teaching.

This training is delivered through theoretical instruction, an open-topic design assignment, and physical laboratory experiments. Theoretical instruction introduces test design and measurement methods. In the open-topic assignment, students select a structural member and develop a complete test plan. Physical laboratory experiments provide training in instrument operation, observation, and teamwork. Although these components have distinct purposes, gaps remain between them. Because of specimen fabrication time and cost, plans for student-selected members are not implemented. Laboratory experiments instead use standard specimens prepared in advance by instructors, with fixed reinforcement and material specifications and loading plans prescribed in the laboratory manuals. Students do not implement the plans they design, and they do not design the plans they implement. Consequently, the bases for parameter selection and loading arrangements are not verified before implementation. Moreover, structural tests are destructive, and loading cannot be reversed once it has begun: design errors remain undiscovered, while errors during implementation cannot be undone. Feedback on plan quality comes primarily from instructor review, which can provide qualitative comments but cannot readily include detailed checks of reinforcement calculations and loading increments for every group.

AI-assisted teaching offers new ways to organize learning in response to this problem. Previous studies have explored updates to knowledge of standards, changes to course structures, and analysis and revision of generated content to support knowledge organization, interactive guidance, and improvement of design work [1]–[3].

The educational value of AI lies not only in generating answers but also in using feedback to encourage students to question conditions, check supporting evidence, and refine their judgments. For a structural testing course, this means combining AI-supported knowledge organization and questioning with disciplinary calculations, direct observation, and instructor guidance, without replacing any of these activities.

This paper proposes an AI-assisted course redesign centered on the development of disciplinary judgment. It organizes knowledge and reference materials around relationships among test decisions, structures iterative test design through questioning and verification, and grounds the interpretation of experimental data in observational evidence. Two teaching cases illustrate the task sequences and assessment requirements, introducing a verification stage before test plans are implemented.

II. REVIEW OF RELATED RESEARCH

A. Participation in Design in Structural Testing Course Reform

Research on structural testing education has long emphasized opportunities for students to participate in design and integrate knowledge.

Improvements in laboratory resources, design training, project grouping, and assessment have been proposed to strengthen the relationship between theory and experimentation [4]–[5]. These approaches extend learning beyond the execution of prescribed procedures to the definition of test objectives, selection of methods, and analysis of results, providing a foundation for experimental research competence.

In terms of learning resources and task organization, the integration of virtual and physical experiments extends learning through virtual familiarization, hands-on operation, and data analysis, helping to address the high cost, long duration, and risk of failure associated with physical tests [6]. Design-oriented experiments connect structural design, load testing, and numerical analysis, encouraging students to develop engineering judgment from observed structural behavior [7]. Visualization of knowledge structures and the organization of teaching content into levels provide additional ways for students to understand relationships among knowledge units [8]. These studies suggest that structural testing course reform should address knowledge organization, task design, and assessment together, while adapting specific approaches to specimen availability and teaching objectives.

B. Course Organization in AI-Assisted Teaching

AI-assisted teaching has expanded from content generation to the organization of course knowledge, learning guidance, and assessment of student work. Organizing course knowledge and updating standards-related content help students connect concepts, while course architecture design seeks to integrate AI support with learning objectives, teaching content, and assessment [1]–[2]. Research that coordinates course content, tasks, and assessment around competency requirements also provides a basis for considering the relationship between AI and the curriculum systematically [9].

Design education emphasizes students' analysis and manual improvement of generated outputs, making the process of developing a design part of learning itself [3]. Research on laboratory courses also indicates that the accuracy of AI responses to complex questions and students' reliance on generated content can affect the educational value of feedback [10]. Together, these studies indicate that verification of AI outputs should become a learning task in which students explain why they accept, revise, or reject a suggestion.

C. Redesign Approach for the Structural Testing Course

The studies reviewed above offer methods for connecting knowledge, developing design skills, and assessing learning processes. Their application to structural testing nevertheless requires a common problem to be addressed: both test design and interpretation of results depend on verifiable disciplinary grounds, yet the course lacks activities that make those grounds explicit. Knowledge learned in separate chapters is difficult to apply to specific decisions, parameter choices and loading arrangements in student-designed plans are insufficiently verified, and interpretations of measured data lack observational support.

Accordingly, this paper proposes three approaches: connecting dispersed knowledge in ways that support test decisions, organizing test design through reasoned questioning and verification, and structuring data processing so that observations and interpretations are checked against each other. These approaches are implemented through theoretical instruction, the open-topic design assignment, and physical laboratory experiments, respectively. Assessment extends across all three components and focuses on the reasoning process and its supporting evidence.

III. APPROACHES TO AI-ASSISTED COURSE REDESIGN

A. Coordinating Learning Tasks Around the Grounds for Judgment

The course redesign targets four competencies: test plan design, laboratory operation, data analysis, and teamwork. Test plan design, data analysis, and teamwork correspond to the three graduation requirement indicators identified above, while laboratory operation provides the practical foundation for developing these competencies. Theoretical instruction connects test tasks, models, loading, measurement, and analysis of results. The open-topic assignment emphasizes parameter selection and justification of design choices. Physical laboratory experiments emphasize proper operation, recognition of phenomena, and analysis of evidence. AI supports knowledge organization, questioning of test plans, and development of interpretations. Students perform key calculations, check sources, and revise their judgments, while instructors design questions, provide disciplinary oversight, and supervise laboratory work. The three approaches correspond directly to the three identified problems. Section III-B explains how knowledge and reference materials can be organized around test decisions to support the application of knowledge. Section III-C explains how questioning and verification can structure iterative design and provide checks on test plans. Section III-D explains how observational evidence can organize the interpretation of experimental data and connect explanations to records. The principal change in teaching organization concerns feedback: specific test questions prompt connections across knowledge units, design submissions include both initial drafts and key revisions, and laboratory reports use original records to support interpretations. All three types of task thus leave verifiable evidence of students' understanding. Together, they allow instructors to examine how students draw on knowledge, resolve disagreements, and reach conclusions, rather than judging learning solely by the completeness of the final written product.

B. Organizing Knowledge and Reference Materials Around Test Decisions

The difficulty in learning theory lies less in understanding individual concepts than in applying them. AI helps organize a map of knowledge relationships that starts with the test task and connects specimen and model design, loading methods, measurement items, and interpretation of results. Instructors provide the syllabus, textbook knowledge units, and checked laboratory manuals and standards-related materials. AI then organizes lists of relevant knowledge and questions linking the topics, after which instructors check coverage and logical relationships. Fundamental topics, including similitude theory, instrument specifications, bridge circuit connections, and temperature compensation, are introduced in the context of the design decisions they support, rather than being taught as isolated topics in separate chapters. These knowledge relationships reflect both the testing sequence and the conditions under which different methods apply. For example, instruction on loading distinguishes between loading control and dynamic excitation. Monotonic loading of a simply supported steel truss and displacement control in the later stages of a concrete beam flexural test are used to discuss how the choice of control variable relates to the stage of structural response. The initial-displacement method for a uniform-strength cantilever steel beam is used to explain the relationship between excitation and free-decay response. Instruction on measurement starts from the performance indicators to be identified and works backward to the required physical quantities, measurement locations, instruments, and interpretation methods, enabling students to justify their measurement arrangements.

Updates to reference materials are integrated with this question-based instruction. Students use general-purpose large language models to search for materials and updates to standards in structural testing, inspection, and monitoring, and explain in class how these relate to the methods they have learned. This activity contributes to the continuous assessment grade. Standard provisions are handled through four steps: locating the original source, checking the edition and clause, determining the scope of application, and preparing an explanation for teaching. The course mainly covers conventional testing methods, while current standards, including the *Technical Standard for Inspection of Building Structures* and the *General Code for Engineering Structures*, have come into effect in succession. Relevant updates are organized by chapter and explained alongside the knowledge relationship map. AI organizes the provisions supplied to it and suggests directions for searching; instructors and students verify whether the provisions are current by consulting original sources. Requirements for structural inspection, design calculations, and test methods have different scopes of application and must be checked accordingly.

C. Structuring Iterative Test Design Through Questioning and Verification

The main difficulty in the open-topic assignment is not writing the plan but obtaining feedback on design choices. The assignment integrates test objectives, specimens, loading, measurement, and implementation arrangements. Each group independently selects its topic and member parameters. AI helps check whether conditions are fully specified, objectives and methods are consistent, and calculations correspond to diagrams.

Different topics require arguments appropriate to their structural behavior: plans involving continuous beams, columns, or slabs must explain key conditions such as supports, axial forces, or punching shear, respectively. Table I relates the five design components to the corresponding AI-assisted tasks.

TABLE II
TEST DESIGN TASKS AND SUPPORTING EVIDENCE FOR VERIFICATION

Design component	AI-assisted task	Main supporting evidence submitted by students
Test objectives and review of existing research	Organize supplied literature and question the relationship between objectives and methods	Original publications, research questions, and proposed evaluation indicators
Specimen design	Check whether dimensions, materials, and detailing are consistent with the test objectives	Structural schematics, parameter sources, and necessary calculations
Loading plan	Check load definitions, supports, loading protocols, and equipment conditions	Loading diagrams, calculation assumptions, and justification for control choices
Measurement plan	Check whether physical quantities, measurement locations, and instruments support interpretation of the results	Measurement layouts, observation methods, and proposed interpretation approach
Equipment, staffing, schedule, and safety arrangements	Identify omissions in resource allocation and organizational arrangements	Equipment requirements, allocation of responsibilities, and implementation conditions

The iterative sequence comprises initial drafting, AI questioning, student verification, and instructor review. Groups first prepare a draft and complete key calculations.

They then provide AI with clearly defined task conditions and design rationales and ask it to identify points requiring verification. Students examine the feedback item by item, explain why they accept or reject each suggestion or require additional information, and prepare a revised plan. Instructors assess the plan together with the supporting reasons for revision. One round of this verification is completed for each of three priority components: specimen design and load-capacity estimation, loading, and measurement. When related parameters change, other parts of the plan are checked as well.

Plan quality is judged primarily by flexible application of theoretical knowledge and the reasoning behind design choices. AI suggestions are checked against textbooks, literature, applicable standards, and independent calculations. Revision notes focus on key disagreements, and students may retain their original judgments when sufficient evidence supports them. Feedback thus improves the plan while making the design process itself an assessable learning outcome.

D. Organizing Laboratory Learning Around Observational Evidence

A common difficulty in laboratory teaching is that students can collect data but struggle to judge whether the data are reasonable. Anomalous readings and interference peaks in spectra are often broadly attributed to “error.” Physical laboratory experiments therefore organize preparation, discussion, operation, and reporting around proposing an explanation, obtaining records, and testing the explanation. Before class, students develop preliminary judgments based on the test objectives, with AI helping them question conditions and organize unresolved issues. During class, they obtain records through instrument operation, observations during loading, and instructor guidance. After class, they check their judgments against theory and data. The five laboratory activities have different training priorities, with corresponding AI tasks, as shown in Table II.

TABLE II
LABORATORY ACTIVITIES AND AI-ASSISTED JUDGMENT TASKS

Laboratory activity	Main training content	Focus of AI assistance and verification
Strain gauge bonding and measurement	Gauge selection, bonding, quality checks, bridge circuits, and compensation	Organize the reasons for operational choices and analyze problems using records of visual inspection, resistance measurements, and insulation checks
Flexural testing of concrete beams	Instrument use, stages of structural response, cracking, and load capacity	Check the evidence used to identify response stages and relate interpretations to load, strain, displacement, and crack records
Shear testing of concrete beams	Failure modes, strain and displacement, and ultimate load	Compare candidate explanations and analyze differences using crack maps, relevant strain records, and material property data
Nondestructive testing of a simply supported steel truss	Calculation of member forces and deformations, methods of joints and sections, discussion of zero-force members, and monotonic loading	Check calculation assumptions and compare judgments about member forces and deformation with measurement records
Testing the static and dynamic characteristics of a uniform-strength cantilever steel beam	Bridge circuit wiring, dynamic data acquisition, and frequency and damping analysis	Organize relationships between channels and physical quantities, and check frequency calculations and response interpretations

Laboratory reports emphasize data processing and evidence analysis. AI may help organize calculation steps, check plotting scripts, and suggest possible causes of anomalies. Students verify units, channels, and loading sequences and retain the original records and processing steps. Explanations of cracking, yielding, abrupt strain changes, or spectral peaks must be linked to the relevant observation conditions. Where evidence is insufficient, students identify the possible causes requiring further investigation and the missing records. During report review, instructors compare the evidence supporting different explanations, bringing the analysis back to specific experimental questions.

E. Assessing the Learning Process Through Disciplinary Competencies

Assessment is organized around the four competencies of test plan design, laboratory operation, data analysis, and teamwork, using design assignments, practical assessments, laboratory reports, and course examinations. Design assignments assess the appropriateness of parameter choices and methods, the grounds for revisions, and innovative thinking. Practical assessments examine instrument use, record quality, and coordination of responsibilities. Laboratory reports assess calculation procedures and the relationship between conclusions and evidence. Classroom tests and examinations assess students' independent understanding.

A brief AI-use statement forms part of the process documentation. It records the tool and version information, date of use, task, key suggestions, verification evidence, and locations of revisions. Instructors assess understanding through students' explanations of calculations and classroom questions, while groups specify each member's contributions to design, calculation, operation, and analysis. Assessment focuses on disciplinary contributions and the quality of judgment. The number of AI dialogue turns and the length of generated outputs serve only as contextual information about the process.

During implementation, instructors first prepare checked course materials and sample questions, then guide students to take increasing responsibility for verification. Where access to AI tools is limited, equivalent tasks can be completed using a common set of feedback materials supplied by the instructor or through classroom discussion. Instructors and students check key calculations, the applicability of standard provisions, and laboratory operations against disciplinary requirements so that tool use remains aligned with course learning.

IV. CASE DESIGNS

One case is selected from the open-topic assignment and one from the physical laboratory experiments to illustrate the organization of iterative design and experimental judgment, respectively. The simply supported concrete beam shear-test case focuses on aligning material parameters with design objectives and follows the questioning approach described in Section III-C. The uniform-strength cantilever steel beam case focuses on aligning specimen conditions with data interpretation and follows the evidence-checking approach described in Section 3.4. Both address the same competency requirement, but the first concerns judgments about design parameters and the second concerns judgments about measured records.

A. Designing a Shear Test for a Simply Supported Concrete Beam

In this case, groups independently design specimen dimensions and reinforcement, estimate load capacity, and determine loading, measurement, and organizational arrangements. The teaching objective is for students to explain how each choice serves the investigation of shear behavior and analyze how different bases for calculation affect the plan. Students first develop a complete draft, then use AI questioning to examine specimen parameters, material values, and the relationships between loading and measurement. Table III summarizes the verification priorities.

TABLE III
DISCIPLINARY VERIFICATION TASKS FOR THE SHEAR-TEST PLAN

Verification component	Main questions	Supporting evidence and outputs
Specimen and failure mode	Do the shear span-to-effective depth ratio, longitudinal reinforcement, stirrup reinforcement, and material conditions support the intended shear behavior? Have other failure modes been considered?	Structural loading schematic, applicable calculation methods, and explanations of parameters
Material parameter values and load capacity	Are the parameters design values, measured values, or converted values? Are they consistent with the requirements of the equations?	Parameter sources, conversion of property measures, and comparative calculations
Loading and measurement	Can the loading increments, load-holding periods, and measurement locations support identification of the target behavior?	Justification for loading arrangements, measurement layout, and proposed interpretation methods

To provide a specific basis for comparison, the instructor uses the specimen and measurement arrangements in the course's Laboratory Manual for Shear Testing of Reinforced Concrete Beams as reference material. The specimen uses C25 concrete, HRB400 longitudinal reinforcement, and HPB300 stirrups. Loading proceeds in 5 kN increments, with each load level held for 2 min. Strain rosettes are placed in the shear failure region, strain gauges on the bottom surface at midspan, and displacement transducers at the supports and midspan. Students first explain the observation objectives served by these arrangements, then check whether the conditions of their own selected topic justify the same approach. These parameters are used for comparative analysis; student-designed plans remain governed by their own research objectives.

Selection of material strength values is the central issue examined in this case. The manual requires cracking and failure loads to be estimated using measured mechanical properties of the materials, whereas plan design also involves material strength design values specified in standards. The instructor therefore sets a task to distinguish among parameter sources. Students first explain the purpose of the calculation and list the strength measures required by the equations, then ask AI to check their meanings, sources, and conversion requirements. A possible prompt is: "Check the meaning and source of each material parameter in the attached load-capacity calculation. Identify any additional test properties and conversion evidence required, and explain which parts of the test plan may be affected by changes in these parameters."

During verification, students distinguish among cube compressive strength, axial compressive or tensile strength, and reinforcing steel strength, and process measured material data using methods approved by the instructor. Existing material test records can demonstrate parameter conversion and comparison of results.

Where measured data are not yet available for a student-selected member, students state the proposed basis for parameter selection and identify the material tests needed before implementation. Numerical values and equations in AI feedback are checked on this basis.

The consequences of parameter selection ultimately affect the loading plan. Material strength design values incorporate partial factors and are conservative for engineering design; when used to predict specimen failure loads, they produce lower estimates. In calculation models where load capacity increases with the strength parameters, lower parameter values lead to a lower predicted failure load. A loading sequence divided on this basis may exhaust its planned increments before the specimen actually fails, leaving observations of the failure mode incomplete. Students investigate this effect through comparative calculations and revise the loading plan in light of equipment capacity and observation objectives. The teaching emphasis is therefore on explaining the relationships among parameter sources, model conditions, and design choices, rather than simply comparing two final numerical values.

Each group submits its plan, key calculations, and revision notes. Instructors assess independent work, application of theory, and originality across the five design components. The outcome of this case is a justified plan for an open-topic assignment. Materials from the physical shear-test experiment serve only as a methodological reference; experimental validation of a student-selected member still depends on whether the corresponding plan is actually implemented.

B. Testing the Static and Dynamic Characteristics of a Uniform-Strength Cantilever Steel Beam

This case uses a uniform-strength cantilever steel beam. The static test includes eight strain measurement locations and a displacement measurement at the loading point. The dynamic test uses the initial-displacement method to determine natural frequencies and damping ratios with added masses of 5, 10, and 15 kg, recording acceleration, dynamic displacement, and two channels of dynamic strain. Teaching proceeds through preliminary judgment, wiring and data acquisition, data analysis, and report review. Table IV lists the main channels and verification tasks.

TABLE IV
MEASUREMENT CHANNELS AND GROUNDS FOR JUDGMENT IN THE STEEL BEAM TEST

Measurement channel	Quantity or arrangement measured	Verification focus
Static strain indicator channels 1–8	Longitudinal strain on the beam surface	Relationship between measured strains and the uniform-strength condition under the corresponding static loading; signs and absolute values at corresponding upper and lower measurement locations
Static strain indicator channel 9	Resistive displacement transducer in a half-bridge configuration	Correspondence among displacement, bridge circuit components, and terminals A, B, and C
Dynamic acquisition channels 1–4	Acceleration, dynamic displacement, self-compensated dynamic strain, and externally compensated dynamic strain	Correspondence between channels and physical quantities, compensation conditions, and signal interpretation

Before class, the question “Which measurement location has the largest absolute strain?” prompts students to compare their experience with prismatic beams against the conditions for a uniform-strength beam. For a prismatic beam, the fixed end has the largest bending moment and therefore the largest strain. In this specimen, however, the section modulus varies along the beam in proportion to the bending moment. The maximum bending normal stress is theoretically the same at each cross-section, so the strain readings at the measurement locations should be similar, with no single location having a uniquely largest value. Groups first develop an explanation from a loading diagram, then describe the support and loading conditions to AI and check whether it identifies the missing geometric information. They subsequently provide the uniform-strength geometry and measurement conditions and compare the assumptions and reasoning in the responses. The comparison focuses on how the conclusion changes as the conditions become more fully specified and whether AI supplies verifiable mechanical reasoning.

Under the corresponding static loading and the assumption of elastic bending, proportional variation of section modulus and bending moment keeps the maximum bending normal stress, M/W , constant. For the same material, longitudinal strains at corresponding points on the upper and lower surfaces are theoretically equal in magnitude and opposite in sign. Students use this relationship to check whether measured absolute strains are similar and analyze deviations in light of measurement locations, bonding quality, loading, and support conditions. This examination turns “uniform strength” from a name into a relationship between loading and cross-sectional properties, providing a common basis for checking both AI explanations and experimental results.

During class, instructors explain the static and dynamic measurement channels and wiring. Students check the AI-assisted channel descriptions against the actual equipment, complete the tests under each condition, and save the records. Dynamic analysis focuses on the relationships among added mass, frequency, and damping. Students specify the conditions being compared, calculate frequencies from the test records, and compare them with software analysis results. Where differences arise, AI helps organize possible checks, including test condition identifiers, sampling settings, data segments, and the selection of periods or peaks. Students then return to the records to check each possibility. Changes in damping ratio are analyzed from the measured results, with the calculation method and data segment documented.

Report review focuses on comparing the conditions and records supporting each explanation. Instructors ask students to explain whether spectral peaks are supported by time-domain signals and test conditions, how structural responses can be distinguished from measurement-induced interference, and which possible causes require further observation. AI assistance thus extends from questioning conditions before class to comparing evidence after class. Operational records, calculation procedures, and revised interpretations together form the assessment materials.

C. Implementation Sequence and Process Documentation

The two cases address test design and experimental judgment, respectively, and use task-specific assessment evidence. The first examines whether parameter choices and revisions are justified; the second examines whether operational records, calculations, and interpretations agree. Implementation progresses from simpler to more demanding activities. Knowledge mapping and source verification come first because they concern only the order of theoretical instruction. Judgment training in laboratory work is introduced through preparation and reporting. The design assignment involves changes to grading and submission requirements and is implemented fully once the teaching and assessment methods have been established.

Both cases generate process records within the teaching materials, including comparisons of plans before and after revision, initial answers to guiding questions and subsequent explanations, instructor feedback, and students' verification notes. These records are used to judge which AI feedback supports learning and which creates additional burdens, allowing the scope of questioning and documentation requirements to be adjusted accordingly.

V. CONCLUSIONS

This paper develops an AI-assisted redesign of the structural testing technology course centered on disciplinary judgment. The redesign organizes theoretical knowledge around test decisions, iterative design around questioning and verification, and experimental interpretation around observational evidence. The grounds for judgment and contributions to teamwork are incorporated into assessment. Teaching content, learning activities, and assessment materials are thus aligned with the same competency requirements.

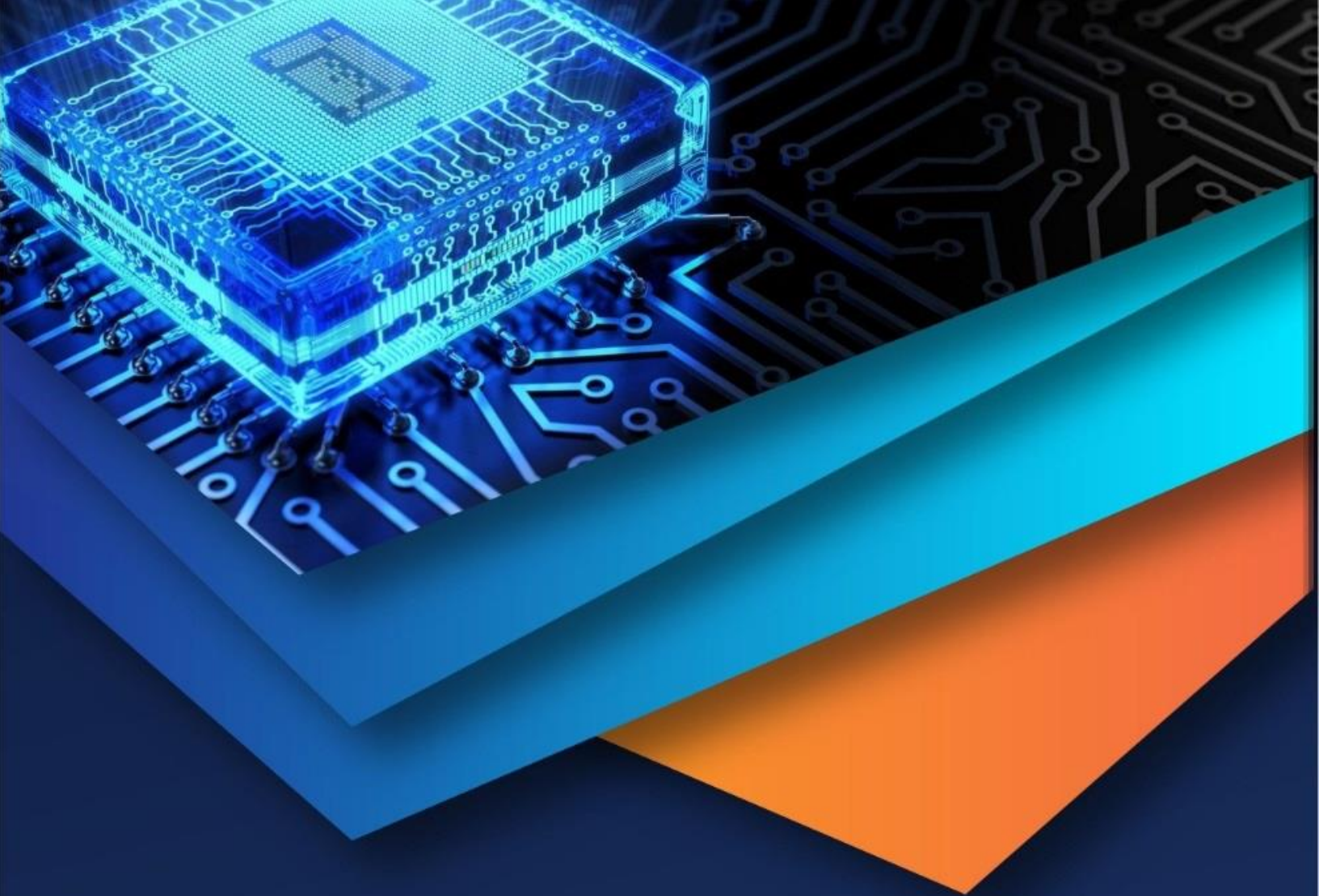
The shear-test design and steel beam experiment cases focus on material parameters and uniform-strength conditions, respectively. They clarify the roles of AI assistance, student verification, and instructor guidance and illustrate how tasks can be designed within the proposed course structure. The course uses general-purpose large language models accessible to students and requires no dedicated platform or additional hardware investment. This paper focuses on the course redesign and case designs. Their effectiveness still needs to be examined through evidence from actual teaching, including revisions to test plans, laboratory reports, and independently completed responses. Future work will use this evidence to refine task arrangements and assessment methods.

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