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An AI-Guided Study Workspace for Teaching Shear–Moment Diagrams (WIP)

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Shear-moment diagrams remain a persistent challenge in engineering courses, from lower-division statics and mechanics of materials to upper-level structural analysis. Student success depends on correctly linking free-body diagrams to equilibrium, maintaining consistent sign conventions, and translating applied loads into shear and moment behavior along a structure. This Work-in-Progress paper describes the design and preliminary evaluation of an AI-guided study workspace that supports learning through a graphical, process-focused approach. The workspace emphasizes a qualitative load–shear-moment scaffold that helps students connect external actions to key diagram features, such as identifying shear jumps at point loads and reactions, assigning slopes under distributed loads, drawing moment behavior from shear, and locating moment extrema where shear is zero. Each problem follows a small set of explicit steps: drawing the free-body diagram, computing reactions, constructing the shear and moment diagrams, and performing consistency checks on signs, continuity, end values, extrema, and units. The AI tutor provides short, targeted prompts when common conceptual errors are detected, encouraging students to reflect on their reasoning rather than supplying final answers.

Implementation occurred in two undergraduate course sections with the same content and pacing. Students completed a traditional problem-solving round without AI support, followed by a second round using an AI-guided Study Mode workspace during the same class session. The AI-guided activity used the same graphical methods emphasized in class and was accessed through a free account configured to support step-by-step reasoning without providing final answers. During the activity, the instructor monitored progress, addressed conceptual questions, and encouraged reflection when errors were identified. Paired, isomorphic problem statements were used across rounds to ensure comparable difficulty and isolate the effect of the practice mode. Students submitted their written work and AI interaction excerpts through the learning-management system, and credit was awarded for completion of required steps rather than solution accuracy.

Evaluation included a short concept check administered before and after the AI-guided workspace activity, related questions on a later course exam to examine carryover of learning, basic process data such as time-on-task and coded error types (e.g., shear jumps, slopes, moment extrema, and boundary checks), and a brief survey of student confidence and perceived mental effort. Traditional and AI-guided practice were compared on these measures, with attention to pre-to-post gains, changes in error patterns, and performance on the later exam. This Work-in-Progress paper describes the study guides and example prompts used in the pilot, which leverage ChatGPT's built-in Study and Learn modes, to illustrate how the activity may be adopted or adapted in similar courses.

Introduction

Shear-moment diagrams are a central topic in mechanics of materials and structural engineering curricula, serving as a foundation for later work in structural analysis and design. Constructing these diagrams requires students to reason from external loading to internal forces using equilibrium and the relationships among load, shear, and bending moment. Despite their importance, engineering education research has shown that shear-moment diagrams remain persistently difficult for students to learn, even after repeated instruction and practice. Prior studies [1-2] show that students commonly struggle to relate applied loads to changes in shear and moment, especially in problems involving distributed loads or multiple discontinuities.

These difficulties are not merely the result of insufficient practice but reflect the cognitive complexity of shear-moment diagram construction. The task asks students to connect several ways of representing the problem, including free-body diagrams, equilibrium equations, qualitative diagram shapes, and quantitative mathematical functions. Research on scaffolded instruction shows that students learn complex technical material better when expert problem-solving steps are made explicit. Strategies like breaking problems into clear stages, encouraging reflection at key points, and giving focused feedback have led to strong learning gains in higher education, including engineering [3].

Intelligent tutoring systems have been shown to be as effective as one-on-one human tutoring in improving learning outcomes in STEM topics [4]. Their effectiveness is greatest when they provide immediate, targeted feedback on students' intermediate steps rather than focusing only on final answers. Recent advances in artificial intelligence have made it possible to deliver this type of scaffolded support at scale. In engineering education, AI-based tutoring systems have demonstrated the ability to support complex problem-solving tasks and significantly enhance the quality of engineering education [5-6].

There is growing interest in using AI to support learning by guiding students without simply providing answers. When used carefully, AI can offer hints, prompts, and feedback that address common mistakes and support step-by-step learning. This study uses the ChatGPT Study and Learn tool to structure the shear-moment diagram problem-solving process and provide timely feedback on common student errors. Implemented in an undergraduate engineering course, the approach breaks problems into stages that reflect expert practice and offers targeted guidance when students struggle. Preliminary assessment and survey results examine its impact on student understanding, error patterns, and perceived confidence when constructing shear-moment diagrams.

This Work-in-Progress study was guided by three research questions: (1) whether AI-guided, scaffolded practice improves student performance on shear–moment diagram construction compared to traditional practice; (2) which categories of errors, such as reactions, shear slopes, moment extrema, and sign conventions, show the greatest change during AI-guided practice; and (3) how students perceive the usefulness, clarity, and cognitive effort associated with AI-guided study relative to conventional problem solving.

Design of the AI-Guided Study Experience

The AI-guided study experience was designed to act more like a coach than an answer-giving tool. Its goal was to make expert thinking visible while still allowing students to work through problems on their own and learn from mistakes. To do this, the experience combined instructor-created visual notes, a step-by-step problem-solving structure, and clear guidelines that limited how students could interact with the AI.

Instructional Materials and Conceptual Framework

Students were provided with instructor-created graphical notes on shear and moment diagrams that emphasized qualitative and quantitative links between loading, shear, and bending moment. The notes used annotated sketches and simple equilibrium and area relationships to show how applied loads translate into diagram features, such as shear jumps at point loads, slopes under distributed loads, and moment slopes based on shear. These notes served as the primary conceptual reference and were uploaded by students into the AI environment at the start of the guided session.

The AI guidance mirrored the structure modeled in the notes. Students first isolated the system with a free-body diagram and computed reactions, then reasoned qualitatively about the shear diagram before constructing the moment diagram. Although this sequence reflects expert practice, it is often implicit in traditional instruction. Making this structure explicit through the AI interaction was intended to help students develop a consistent and repeatable approach to shear-moment diagram problems.

Guided Study Mode

Scaffolded Problem-Solving Workflow

To avoid over-reliance on AI or answer copying, students used ChatGPT in Study Mode under explicit guardrails. At the start of the activity, students uploaded the instructor's graphical shear-moment notes and pasted a standardized "Study Mode Starter" prompt from the course handout:
"I'm practicing shear and moment diagrams using my instructor's graphical notes. Don't give me final answers. Please tutor me by: (a) checking my FBD and reactions, (b) asking targeted questions about shear jumps/slopes and where $V = 0$, (c) guiding me to sketch M from V, including

any jumps at applied couples, and (d) ending with consistency checks on end values, extrema, units, and signs."

Students were instructed to show their work before requesting feedback, to indicate which step they were working on (FBD, reactions, shear, or moment), and to ask for a check or hint rather than a solution. The intended interaction model was step-focused coaching rather than answer generation. In representative exchanges, after a student posted reaction values, the tutor asked the student to write the full moment equilibrium equation, including the sign of the applied couple, before proceeding. Although the AI sometimes confirmed intermediate calculations, it did not generate complete shear or moment diagrams and instead advanced one step at a time. The correct solutions were not preloaded into ChatGPT, and all final diagrams were completed on paper while the instructor circulated to monitor interactions and address inconsistencies. Students were also reminded to verify AI responses against equilibrium and graphical consistency checks if a response appeared unclear or incorrect. These expectations were reinforced through written instructions and a brief in-class demonstration.

Classroom Implementation and Data Collection

The AI-guided study activity was implemented in two undergraduate Mechanics of Materials courses during a 75-minute class session focused on shear and moment diagrams. Students were informed in advance through a class announcement outlining the activity, technical requirements, preparatory steps, and instructor-provided materials.

The session was divided into two rounds. In Round 1, students solved shear-moment diagram problems by hand using their class notes, without AI support, and their work was collected at the end of the round. In Round 2, students solved isomorphic problems using ChatGPT in *Study Mode* as a coaching tool. Students uploaded the instructor's notes and pasted the standardized Study Mode Starter prompt before beginning work, then proceeded at their own pace while the instructor circulated to answer conceptual questions and monitor AI use. Emphasis was placed on reasoning quality rather than speed or numerical precision. After the session, students provided brief excerpts of their AI-guided interactions as evidence of process, while all diagrams were completed and collected on paper in class.

Round 1 and Round 2 Evaluations

Student learning was evaluated using paired, isomorphic shear-moment diagram problems completed during two problem-solving rounds within the same class session. Two sets of isomorphic problem pairs were developed (Figure 1), and students were randomly assigned to one set such that each student solved one problem without AI guidance (Round 1) and one corresponding isomorphic problem using the AI-guided Study Mode (Round 2). In Round 1, students used their usual in-class, paper-and-pencil approach, while in Round 2 they solved a problem of comparable structure and difficulty with the AI serving as a coaching tool. Each Round 2 problem mirrored its Round 1 counterpart in loading type, boundary conditions, and required reasoning (e.g., simply supported beams with point loads and an applied couple, or cantilever beams with a distributed load and end couple).

In both rounds, students constructed free-body diagrams, computed reactions, and drew shear and bending moment diagrams using the graphical method emphasized in class. Student work was evaluated using a 10-point analytic rubric applied consistently across both rounds: (1) free-body diagram and conventions (2 points), (2) reactions (2 points), (3) shear diagram construction (3 points), and (4) moment diagram construction (3 points). All diagrams were scored by the instructor using the same rubric. Future implementations will incorporate a second independent rater to formally establish inter-rater reliability.

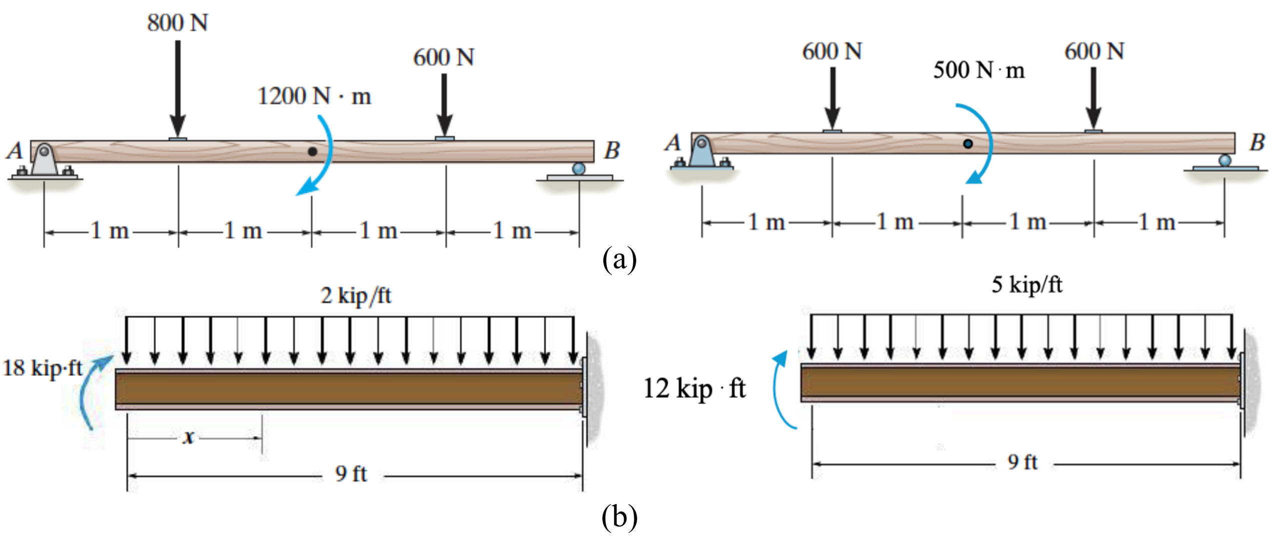

Figure 1. Examples of paired isomorphic problems used in non-AI and AI-guided problem-solving rounds: (a) simply supported beams with point loads and applied couples, and (b) cantilever beams with distributed loads and end moments. Adapted from [7].

Student Survey

In addition to the problem-based evaluations, students completed a brief post-activity survey to capture their perceptions of the AI-guided experience. The survey focused on aspects not easily inferred from written work, including the clarity of the step-by-step workflow, the usefulness of AI prompts for identifying and correcting errors, confidence in constructing shear and moment diagrams, and perceived differences between conventional and AI-guided practice. The survey included both Likert-scale and open-ended questions.

Preliminary Results

Pre- and Post-Activity Evaluation Results

Student performance on the shear-moment diagram evaluations improved from the non-AI problem-solving round to the AI-guided round. As shown in Figure 2, average scores increased across all rubric categories, with smaller gains for free-body diagrams and reactions, where performance was already relatively strong, and larger gains for shear and moment diagram construction. These improvements reflect stronger student ability to identify shear jumps, interpret slopes under distributed loads, relate shear to moment diagram shape, and recognize key features such as moment extrema and sign conventions. Overall, the results suggest that the AI-guided workflow was effective in supporting qualitative interpretation and diagram construction.

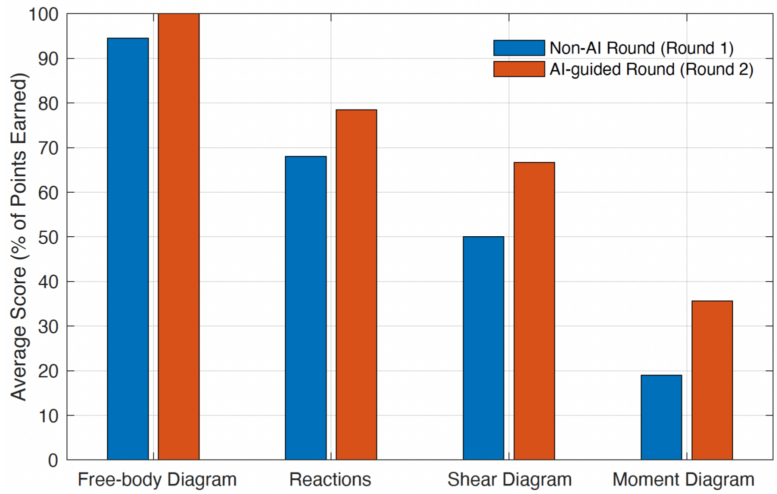

Figure 2. Student performance by rubric category on paired, isomorphic problems during non-AI (Round 1) and AI-guided (Round 2) problem-solving rounds.

Student Survey Results

Survey responses indicate generally positive student perceptions of the AI-guided Study Mode experience, particularly in supporting process awareness and error detection. Figure 3 shows the distribution of student self-reported confidence ratings before and after the AI-guided activity, using a five-point scale where 1 indicates very low confidence and 5 indicates very high confidence in constructing free-body, shear, and moment diagrams. While confidence levels varied in both cases, the post-activity distribution shows a modest redistribution of responses away from the lowest confidence ratings and toward mid-range and high confidence levels. Correspondingly, the average self-rated confidence increased slightly from 3.34 before the activity to 3.45 after the activity. Although the change is modest, these results suggest a positive effect of the AI-guided session on students' perceived confidence.

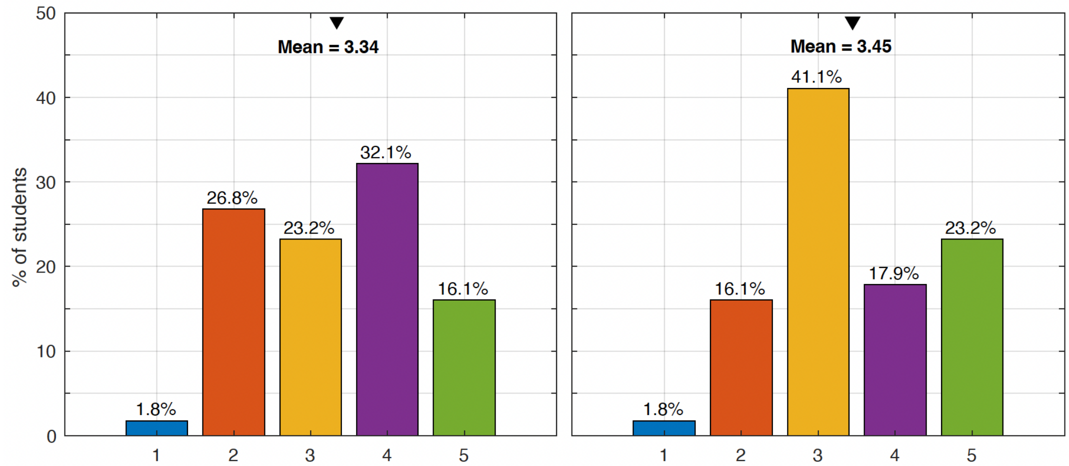

Figure 3. Student self-reported confidence in constructing shear-moment diagrams before and after the AI-guided Study Mode activity (1 = very low confidence, 5 = very high confidence).

Figure 4 summarizes student responses to Study Mode experience questions related to error correction and process understanding. Question 1 (Q1) asked whether the AI tutor helped students notice and correct mistakes, and Question 2 (Q2) asked whether the tutor's questions improved understanding of the problem-solving process rather than simply helping students reach a final answer. A majority of students selected agree or strongly agree for both questions, indicating that many students perceived the AI guidance as supportive of reflection and learning. At the same time, a substantial portion of students selected neutral, suggesting that the perceived impact of Study Mode varied across the class. Overall, these responses support the intended role of Study Mode as a guided learning tool that promotes process awareness rather than answer provision.

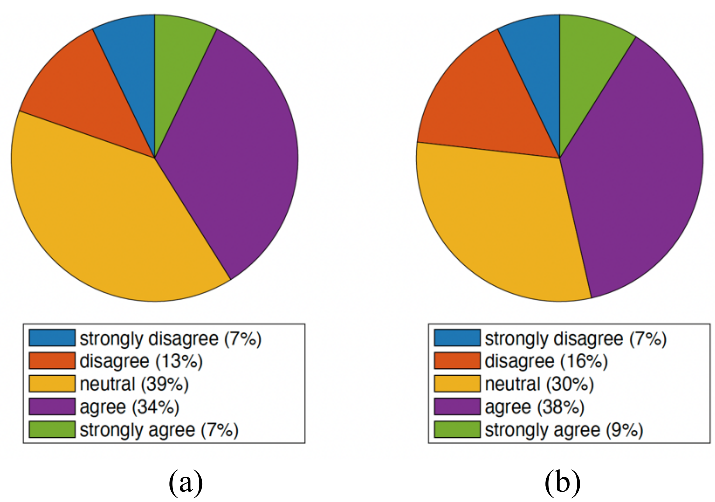

Figure 4. Student responses to two Study Mode experience questions addressing (a) error correction and (b) understanding of the problem-solving process.

Most students reported moderate mental effort during the Study Mode round, with relatively few indicating low or very high effort, suggesting sustained cognitive engagement without excessive cognitive load. Consistent with this pattern, most students exchanged fewer than seven back-and-forth messages with the tutor per problem, indicating focused use of the AI for guidance and feedback rather than prolonged interaction or dependence.

Open-ended survey responses further contextualize these findings. Many students reported that the AI prompts helped them identify and correct common errors, particularly related to sign conventions and diagram features. For example, students noted help with *"catching sign errors," "clarified sign conventions for the diagram, starting approach,"* and *"understanding how the relationship between the moment and shear works."* Others highlighted support for qualitative reasoning about diagram shape, noting that Study Mode helped with *"understanding how to determine if moment diagrams are concave up or down in certain scenarios"* and *"made me rethink why was I was doing certain steps."*

Several students also emphasized that the structured questioning encouraged a more deliberate approach. One student noted that *"Study mode outlined the steps needed to draw a moment diagram,"* while another commented that it helped them think *"about more than just the problem."* At the same time, some students expressed frustration with aspects of the AI interaction, particularly related to time and reliability. Comments such as *"it takes longer to use AI since there is a lot of back-and-forth typing," "GPT's responses were overwhelmingly long," "sometimes ChatGPT is wrong,"* and *"I like that it helps explain the process of solving problems, but how it explains it isn't the clearest. Definitely better to learn from in person teaching or a YouTube video."* highlight the importance of clear guardrails and active instructor guidance when integrating AI tools into problem-solving activities.

Overall, the survey results suggest that students perceived the AI-guided activity as most valuable for supporting process understanding, self-checking, and reflection, rather than for efficiency or answer verification.

Discussion

The preliminary results suggest that the AI-guided study workspace supported student learning primarily by making the problem-solving process more explicit and structured, rather than by simplifying the task itself. Improvements were concentrated in shear and moment diagram construction rather than free-body setup, suggesting that the scaffolded prompts were most impactful during diagram interpretation, particularly in reasoning about shear jumps, slope direction, moment curvature, and extrema where $V=0$. Survey responses further indicate that students perceived the AI as helpful for noticing errors and reflecting on their reasoning, particularly with respect to sign conventions and the relationship between shear and bending moment.

Importantly, the AI functioned as a complement to, rather than a replacement for, instructor support. The guided prompts appeared to emphasize conceptual reasoning alongside procedural checks, consistent with the intended role of the AI as a scaffolded study partner. Overall, these findings align with prior work on scaffolding and intelligent tutoring systems, which suggests that AI support is most effective when guidance is deliberately constrained to emphasize process, reflection, and targeted feedback rather than solution generation [8-10].

Several limitations should be acknowledged. Because students completed the non-AI round before the AI-guided round within the same session, improvements in Round 2 cannot be fully separated from practice or warm-up effects despite the use of isomorphic problems. The findings should therefore be interpreted as exploratory rather than causal, and future work will consider counterbalanced designs to better isolate the contribution of AI-guided scaffolding.

Time-on-task also warrants further study. Although students were asked to record elapsed time, compliance was inconsistent, limiting quantitative comparisons of efficiency. Future implementations will incorporate structured time tracking to better evaluate learning gains relative to time investment. Differences in prior experience with generative AI may also have influenced comfort and interaction quality, raising equity considerations. Finally, as this study focused on shear-moment diagrams in Mechanics of Materials, additional research is needed to examine transferability to other civil engineering topics.

Conclusions

This Work-in-Progress paper reports preliminary findings from a single-session implementation of an AI-guided, scaffolded study activity conducted in two undergraduate Mechanics of Materials courses. The results should be interpreted with appropriate caution, as the sample size was modest, the intervention was limited to one class session, and no parallel control section was available during the same term. Although paired, isomorphic problems were used to compare non-AI and AI-guided problem-solving rounds, longer instructional exposure and repeated practice will be necessary to examine the durability of observed effects.

Despite these limitations, the study demonstrates the feasibility of using AI as a deliberately constrained study partner to support engineering problem-solving. By combining instructor-authored notes, a structured problem-solving workflow, and targeted AI prompts, the study workspace made expert reasoning more explicit without automating solutions. The preliminary results suggest that this approach can support process awareness, error detection, and student confidence. Ongoing and future work will expand implementation across additional sections and terms and will examine longer-term learning, retention, and transfer to better understand the instructional potential of AI-guided study tools.

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