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Effectiveness of Just-In-Time Teaching on Helping Students Achieve Lower Order Learning Goals in a Mechanics of Materials Class

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Abstract

Just-in-Time Teaching (JiTT) is a pedagogical practice first developed to help non-traditional students improve their learning and has been adapted into many different teaching contexts. The backbone of JiTT involves students completing an online assignment, called a warm-up, based on an assigned reading. Students have up until a few hours before class starts to complete the assignment. In those few hours before class the instructor reviews student responses and adapts their plan for class according to the students' current knowledge level. This paper describes the implementation of JiTT in an undergraduate Mechanical Engineering Mechanics of Materials course, with the goal of using it to help students achieve learning objectives on the lower end of Bloom's taxonomy before class. Short answer type questions for learning objectives on the understand level of Bloom's taxonomy and multiple-choice questions for learning objectives on the analyze level are shown to moderately achieve this goal. The feedback loop between students and instructor was instrumental in determining how to best use class time to support student learning. Recommendations for best practices, including how ChatGPT can be leveraged to quickly summarize student responses, based on the instructor's experience and student feedback, are given.

Introduction

Studies have shown that students who read assigned textbook sections before coming to class find it beneficial for their learning. They have also shown that today's engineering students rarely read the textbook [1]. Just-In-Time-Teaching (JiTT) is a pedagogy that aims to help students effectively prepare for class and develop good study habits [2]. It was first developed in the late 1990s with the advent of the internet at Indiana University Purdue University Indiana and the U.S. Air Force Academy to help non-traditional students in STEM courses effectively prepare for class and improve their learning [3].

JiTT involves assigning students a reading and an online assignment, called a "warm-up," associated with that reading. The warm-up assignment is given to students well in advance of the due date, which is a few hours before class time. The just-in-time aspect comes from the instructor reviewing the student responses in those few hours before class and gauging what learning goals the students did or did not attain. The instructor then adjusts their lesson plan according to the level of knowledge that students will have coming into the class. JiTT has been shown to provide a scalable method for creating a regular feedback loop between student and instructor [3]. If students put forth their best effort in answering warm-up questions, instructors have an opportunity to identify misconceptions, knowledge gaps, and concepts that students have

already grasped prior to class. The instructor can then focus class time on the topics and concepts in which students are most in need of support.

JiTT has been shown to increase student learning relative to classes that do not use this method [4]. In addition, warm-up assignments promote good study habits by requiring frequent, short spurts of studying throughout the course rather than cramming right before major exams [3]. Warm-ups also promote motivation, if used effectively. Effective use of JiTT includes explaining the learning benefits of the warm-up exercises on the first day of class, making the assignments low-stakes in terms of grades, using open-ended questions, and creating a supportive environment where mistakes are seen as part of the learning process [3].

There is no one way to implement JiTT, and how it is deployed varies depending on the instructor's approach to teaching, the nature of the course, and the goals for the warm-up assignments [3]. In one biology course [3], warm-up assignments based on concepts rather than mathematical proficiency showed greater learning gains. Both methods showed learning gains over a traditional lecture-based course.

This study seeks to determine whether JiTT can be leveraged to help students achieve lower order content mastery on Bloom's taxonomy prior to class so that class time can be spent on higher order content mastery through active learning. Active learning pedagogies have been shown to increase student engagement, improve retention of information, increase exam scores, and decrease failure rates by a third [5, 6]. One of the challenges cited by instructors using active learning is lack of time [6]. Bloom's taxonomy, shown in Figure 1, is a framework used to categorize the components of learning from straightforward to complex [7].

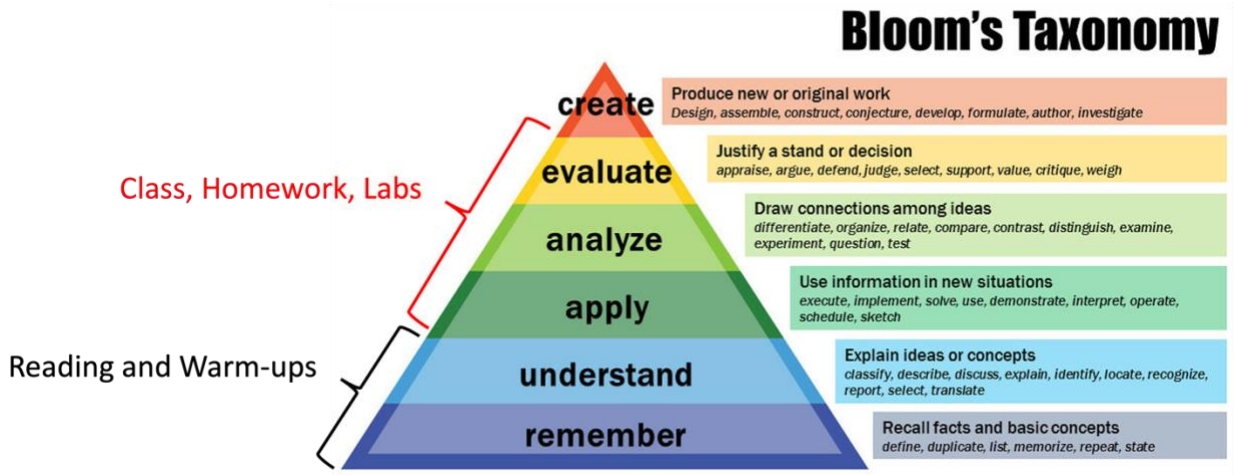

Figure 1. Bloom's taxonomy. Reading and warm-up assignments are intended to help students achieve the lower order learning goals before class. Class time, problem-solving homework, and labs are meant to achieve higher order thinking skills. This image was shown to students on the first day of class to help them understand the importance of readings and warm-up assignments. Image from Vanderbilt University Center for Teaching, CC BY 2.0, via Wikimedia Commons

Methods

Structure of Warm-up assignments in the course

JiTT was used in two sections of an undergraduate mechanical engineering Mechanics of Materials (often called strength of materials) course in the Fall 2023 semester, both taught by the author. This is an intermediate level, lecture-based course that teaches the fundamentals of solid mechanics. It has a separate lab corequisite, and most students are either sophomores or juniors. Each section met every Monday, Wednesday, and Thursday for 65 minutes, one at 9:15 am and the other at 1:35 pm. In Fall 2023 the 9:15 class had 51 students enrolled and the 1:35 class had 49 students enrolled, for a total of 100 students.

The summative assessments for this course largely focus on problem-solving. The final course grade is based on weekly homework problem sets (10%), weekly 15-minute quizzes (35%), one midterm exam (20%), and one final exam (35%). Formative assessment is largely performed through active learning in class, such as think-pair-share, polls, and small group work.

Warm-up assignments were part of the homework grade. There were two warm-ups per week, due every Monday and Thursday at 7:00 am, approximately 2 hours before the earliest class. Each warm-up was worth 5 points, half of one problem on the weekly problem sets, making the warm-ups collectively worth 1.5% of the final course grade. The warm-ups were graded automatically by Canvas for completion, not accuracy, to discourage cheating and encourage participation. The reading assignments and warm-ups for each week were released no later than noon the preceding Friday to ensure students had ample time to complete them.

The reading assignments came from the textbook and warm-ups were created and administered in the Canvas LMS for the course. An example of the instructions and questions for one reading are shown in Figure 2. A variety of question types were used, including multiple choice, choose from a dropdown, fill in the blank, calculation, and short answer, which are all easily created in Canvas quizzes. In addition, every warm-up assignment ended with the question, “After reading the textbook and completing this assignment, what are you still confused about? If nothing is confusing, what part of this reading/assignment did you find the most interesting?” [4]. This is often called a “muddiest point” question, with the purpose of understanding student’s current level of understanding [8].

Warm-ups were designed by examining the learning goals for each chapter and identifying which ones were lower on Bloom’s taxonomy – these were the learning objectives the warm-ups aimed to help students achieve.

Preparing students for warm-ups

Instructors using JiTT have noted the importance of preparing students for the assignments and motivating them to complete them [3]. Many warm-up questions ask for short explanations and

reasoning, so there was an additional concern that students would use ChatGPT or other large language models (LLMs) to produce answers which they could copy and paste into their submissions. Although the warm-ups were not graded for accuracy, this would defeat the entire purpose of the exercise. To preempt this, on the first day of class, the objective of the warm-up assignments was explained to students with the image in Figure 1. Specifically, they were told the goal of the warm-ups was to help them achieve the lower order goals before class so class time could be spent on the higher order goals.

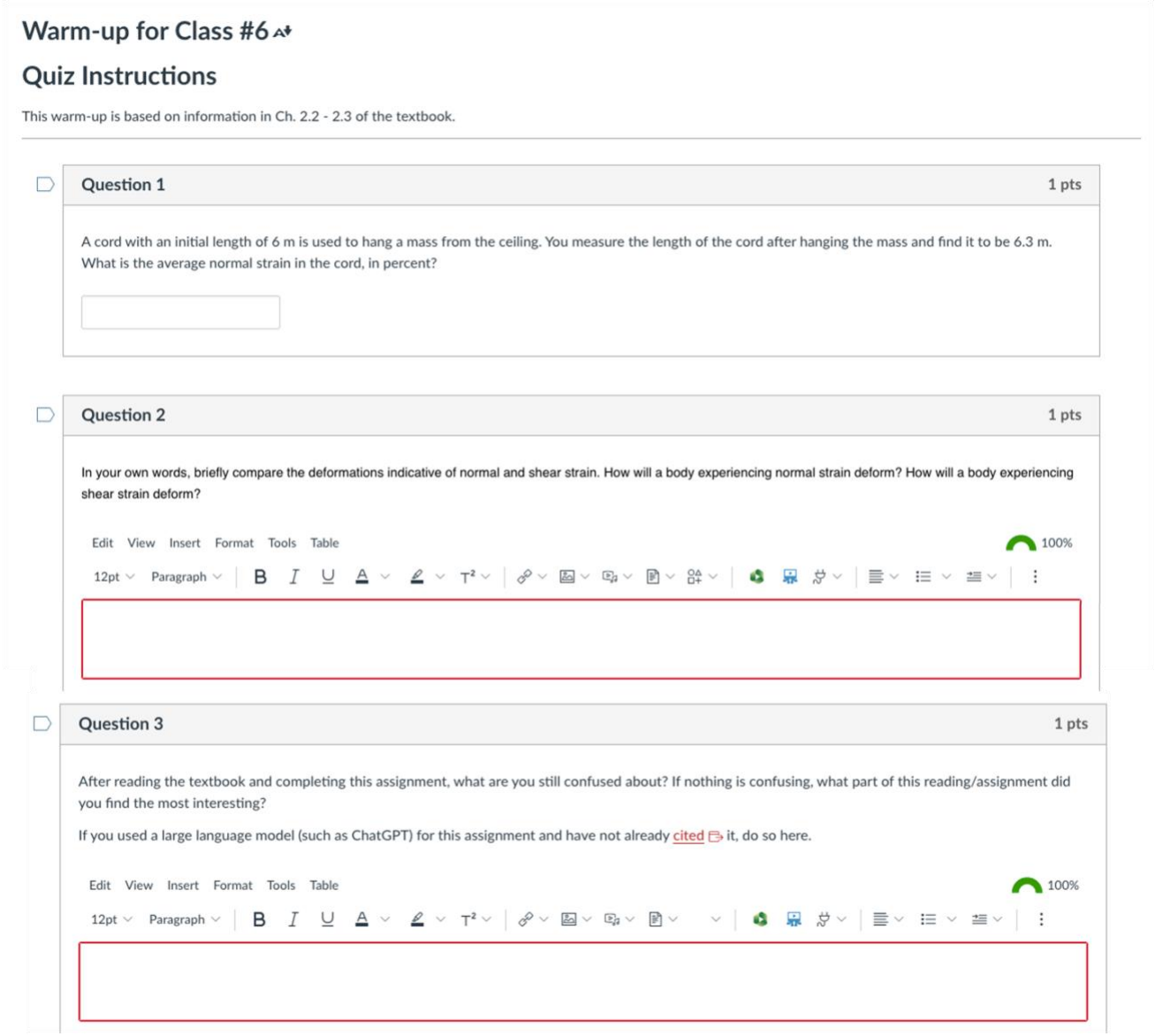

Figure 2. An example of a warm-up assignment created in Canvas quizzes. Question 1 is a calculation question, question 2 is a short answer question, and question 3 is the "muddiest" point and AI citation question.

Students were also provided a policy on generative AI use for the course. It stated, in part, "To achieve the goal of learning, the following policies on using AI will be applied in this course:

- You may not copy and paste any question on a warm-up, homework, or any other course material directly into an LLM. You may ask general, explanatory questions such as "What types of loading may occur in an axial member?"
- You may not copy and paste responses from an LLM and submit it as your own work. Everything you submit must be your own work and in your own words.
- You must properly cite your use of LLMs: https://apastyle.apa.org/blog/how-to-cite-chatgpt. This includes stating what model you used, what you entered into the chatbot and what it produced. This is applicable to all submissions, including **warm-ups, homework, and lab reports**.
- You must be prepared to explain any code generated by an LLM to me and the course TAs. **If you do not understand the code, do not use it**.
- If you are unsure if you are using LLMs appropriately, do not hesitate to reach out to me.

Students were also warned that sometimes what ChatGPT produces looks very confident to the untrained eye, but is actually nonsense. Each warm-up assignment ended with a question asking them to cite their AI usage. Interestingly, no student ever cited AI usage.

Synthesis of student responses to the warm-up

Analyzing 100 student responses in the two hours prior to class was a daunting task. Multiple choice, calculation, or fill in the blank questions could be quickly reviewed in Canvas, but the responses to the open-ended and muddiest point questions were more challenging to synthesize quickly and thoroughly.

ChatGPT was found to be an effective tool to summarize student responses to the muddiest point question. Each morning after the deadline had passed, student responses were downloaded from Canvas into an Excel sheet. The responses to the last question were copied and pasted into ChatGPT with the prompt:

> *I asked students what they found most confusing or interesting about an assigned reading. Their responses are below. Summarize them according to what was interesting and what was confusing.*

Thankfully, the responses did not need to be formatted or edited for ChatGPT to distill rows of text into a short, concise list. The first few times this method was employed, the efficacy of ChatGPT's summary was verified with the author's own review of the student responses. It was found to be both an exhaustive and accurate reflection of what the students said. An example of one of ChatGPT's summaries can be found in the Appendix.

ChatGPT was less effective at analyzing student responses to the short answer questions. Initially, ChatGPT was prompted to analyze responses for inaccuracies, misconceptions, etc. One such prompt was:

I prompted students with the question 'In your own words, briefly compare the deformations indicative of normal and shear strain. How will a body experiencing normal strain deform? How will a body experiencing shear strain deform?' Their responses are below. Group similar responses and summarize the groups.

After reviewing ChatGPT's analysis and doing a manual analysis, it was clear that what ChatGPT produced was inaccurate and did not reflect the student's actual responses.

ChatGPT did prove useful for analyzing one specific type of short answer question: those that asked students to explain a concept or term in their own words. For the most part, responses that included certain keywords demonstrated full understanding of that concept. While ChatGPT could not determine the accuracy of student responses, it could list responses that included a set of key words that would be part of any adequate explanation.

To use ChatGPT effectively and efficiently for this analysis, the CONCAT function in Excel was used to concatenate a number at the beginning of every response. The resulting column of data was copied and pasted into ChatGPT along with a prompt asking it to identify submissions with certain key words. As an example, the prompt provided to ChatGPT for the student responses to "In your own words, expain what stress is" was:

A set of student responses are below. Categorize the responses that include the following key words:
Group 1 – "internal force" and "area"
Group 2 – "intensity"
Group 3 – "internal force" only'

ChatGPT provided a numbered list for each group. These numbers were then pasted back into Excel, converted from text to data, and the VLOOKUP function was used to quickly mark individual responses as correct, partially correct, or incorrect. Generally, Group 1 was considered a response that indicated the learning goal had been met, and groups 2 and 3 as indicating the learning goal was almost met, though this determination was question specific. All unlisted responses were checked and categorized individually by the instructor.

Prompting ChatGPT in this manner – with clear, specific, and explicit instructions – was found to produce a high rate of accurate classifications. It would miss many responses that should have been sorted into one of the groups, but leaving any space for ChatGPT to make its own interpretation led to many incorrect classifications. Through much trial and error, it was determined that writing the prompt in such a way that does not allow ChatGPT to interpret or assume anything is the best way to avoid false positive or negatives.

Using Warm-ups in class

For most classes, the answers to all warm-up questions were summarized on slides and shared at the beginning of class, starting with the muddiest point responses. For open-ended questions, one or two anonymous student responses were shared on the slides [3]. The class would then discuss the strong points of the explanation and anything that was missing or incorrect.

A peer-instruction model was used for multiple choice and dropdown questions [3]. If more than 70% of the class got the question correct on the warm-up, a few minutes in class were spent explaining the correct answer, and perhaps more importantly, why the other options were incorrect. If less than 70% of the class got the answer correct, the relevant material was reviewed and students were asked to revisit the question with their neighbors in the classroom. After a few minutes of discussion, students would re-vote and/or a volunteer was asked to explain their thinking.

For calculation questions, students were provided with the worked-out answer [6], both electronically through Canvas and as a print-out given in class. The instructor briefly walked them through the steps and answered questions. Students were then tasked with solving a different, slightly more advanced problem with their neighbor, which was then reviewed by the instructor in class.

Results

On average about 70-80% of students completed each warm-up assignment. While significant, the goal was 100% participation. Increasing the number of points for the assignments might help increase warm-up completion rates, though the tradeoff is increasing the stakes. Several students stated that they would forget to do the assignments, so some sort of automated reminder mechanism could be helpful. Part of the feedback from the mid-course survey, discussed below, was to adjust the due date on Canvas so it would appear in student's to-do list the day before.

Student perception of warm-ups

A midcourse survey was administered to students in either week 4 or 5 of the semester and asked, among other things, to what extent the warm-up assignments were helpful to their learning. The same question and a few others about the warm-up assignments were posed again in an end of semester survey (separate from the university administered student evaluation of teaching survey). Results from both surveys as well as the mid-semester survey from Spring 2023, in which JiTT was not used, are shown in Figure 3. Student perception is overwhelmingly positive.

One of the most notable takeaways is that before using JiTT, students for the most part were not reading the textbook at all. In Spring 2023, when JiTT was not used, 42% of respondents chose

N/A in answer to the question “To what extent have the before class readings been helpful to your learning?” in a mid-semester survey. One student comment says it all: “I find the outside readings less helpful because everything is explained easily and well in class.” In the Fall 2023, when JiTT was implemented, 79% of students said the readings were either somewhat helpful or very helpful in the mid-semester survey. One student quote from the mid semester survey emphasizing this is “The warm ups and readings are actually helpful to understanding concepts before they are developed in class.”

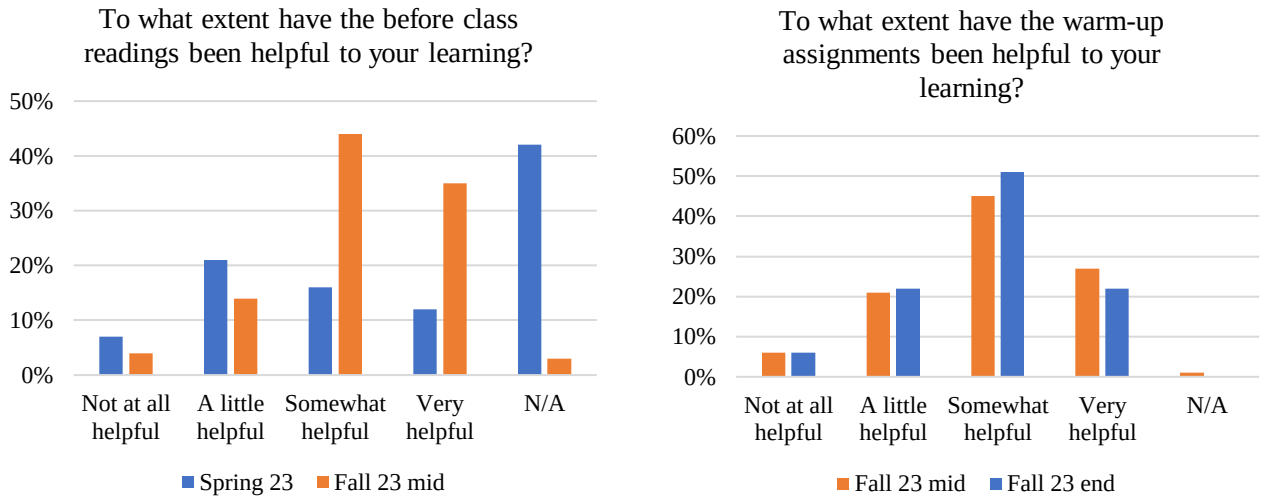

Figure 3. Student responses to feedback surveys. The Spring 23 and Fall 23 mid surveys were sent in either weeks 4 or 5 of the 14 week semester. In Spring 2023, there were no warm-up assignments. The Fall 23 end survey was sent out in the last week of the semester.

Likewise, 72% of students said the warm-ups were either somewhat or very helpful in the mid-semester survey, and 73% said the same in the end-of-semester survey. A quote from those surveys that emphasize this is: “I enjoy the warm-ups. Completing a warm-up familiarizes me with the material and helps guide me towards key concepts. I often get lost while reading engineering textbooks, so the warm-up questions help center my attention and allow me to focus on relevant/important information.”

Not everyone was thrilled with the warm-up assignments, though they were in the minority. 6% of students in both the mid- and end-of-semester surveys said the warm-ups were not at all helpful to their learning. One quote emphasizing this: “The warm ups do so much more harm than good. I often spend valuable lecture time trying to unlearn the concepts I tried to teach myself so I could complete the warm up…” This quote was particularly interesting from an instructor’s point of view, as this student’s experience is indicative of the work and frustrations that are part of the learning process. Whether or not this “unlearning” would need to happen with or without the warm-ups is an interesting question.

Table 1. The types of questions used to target a level of mastery on Bloom's taxonomy.

	Understand	Apply	Analyze
Calculation	0	3	1
Dropdown	1	0	4
Fill in the blank	0	0	6
Multiple choice	2	0	14
Short answer	12	3	4
Short answer/MC	1	0	0

Effectiveness of warm ups on student mastery of lower order skills

Each question in the warm-up assignments targeted a specific learning goal for the course, concentrating on the levels of understand to analyze on Bloom's taxonomy. Table 1 shows the number and types of questions used for each taxonomy. Most questions targeted either understand or analyze. Understand learning goals were most frequently assessed using a short answer question type, and multiple choice was most frequently used for analyze. Because these two taxonomy levels and question type pairs had the most data, they were further analyzed to determine how effective they were at helping students meet the learning goals.

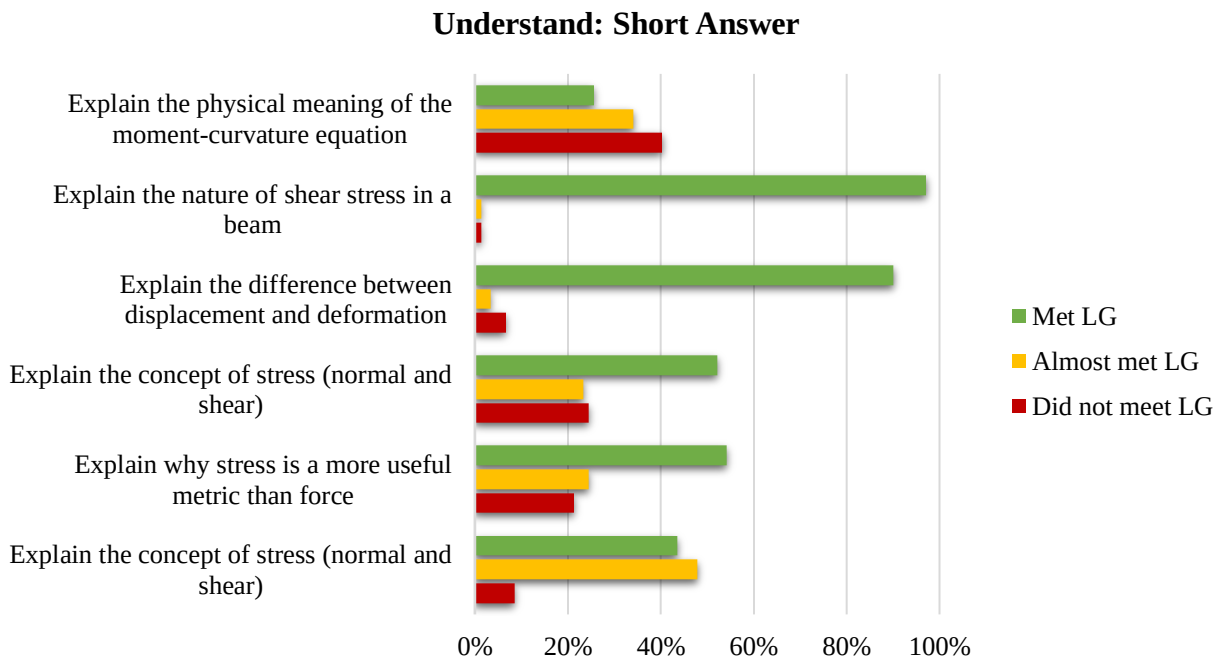

Figure 4. Percentages of responses that indicated the student had met, almost met, or not met the learning goal of understand using short answer questions. Specific goals of each question are listed.

Student responses to short answer questions were classified either individually by the instructor or with assistance from ChatGPT, as detailed previously, as either having met the learning goal

(LG), almost met the LG, or not met the LG. The results are shown in Figure 4 for a subset of these questions. For these questions, an average of 60% ± 28% of students met the learning goal, 22% ± 18% of students almost met the learning goal, and 17% ± 14% did not meet the learning goal, where the ± is a standard deviation. While the average of meeting the learning goal is high, it is also relatively variable. It is worthwhile to note that students did not meet the learning goal on only one of these questions.

Student responses to multiple choice questions were analyzed using the survey statistics feature in Canvas. The results are shown in Figure 5. For these questions, an average of 62% ± 23% of students met the learning goal, 16% ± 24% of students almost met the learning goal, and 22% ± 12% did not meet the learning goal, where the ± is a standard deviation. Again, the greater proportion of students met the learning goal on these questions.

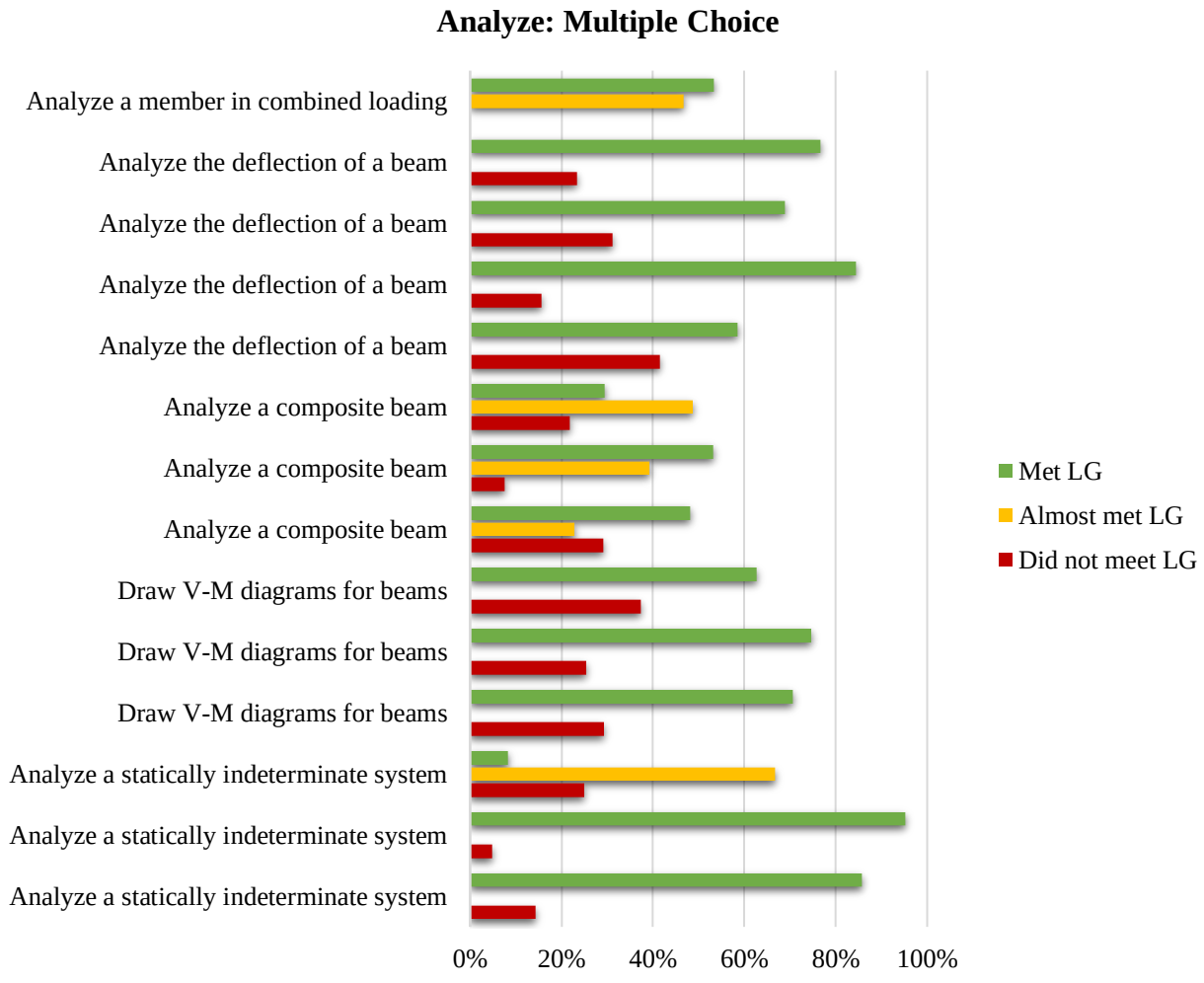

Figure 5. Percentages of responses that indicated the student had met, almost met, or not met the learning goal of analyze using multiple choice questions. Specific goals of each question are listed.

Some multiple choice questions only had answer choices that either did or did not meet the LG. Those questions will necessarily show that 0% almost met the LG. Other questions had answer

choices that indicated the LG was almost met. For example, when choosing the correct shear force diagram for a loaded beam, students may have selected the option that had the correct *V* values at key locations, but not the correct profile (linear vs parabolic) between those locations.

Discussion and Recommendations

Warm-up design

It is worthwhile to learn the best way to use your LMS before starting to create the warm-up assignments. For instance, creating questions in the question bank of Canvas quizzes allowed for organization of questions by chapter, as well as providing a master copy of the questions that could then be imported into individual assignments.

With 100 students, it is not recommended to include more than two short answer questions on one warm-up assignment. The time required to analyze those responses, especially if ChatGPT cannot be used, was prohibitive. It is possible that ChatGPT, or another LLM, could be better leveraged to analyze student responses accurately and speed up this analysis. Because this is such a new tool this author and many others are still learning how to use it.

That being said, there is a strong argument for including as many short answer questions as possible. The nature of the response type allows a richer picture of how students understand (or don't understand) the concepts being assessed than would be possible through a multiple choice, dropdown, or calculation type question. The latter question types do not give insight to the student's thought process, they simply tell you whether they got the question right or wrong. Having the students write out their thoughts helps draw out misconceptions and gaps in knowledge.

For example, one of the short answer warm-up questions assessing understand level learning goals was "In your own words, explain what makes shear stress different from normal stress." Most students were able to identify that shear stress acts parallel and normal stress acts perpendicular. But an important misconception was identified through their responses – many of them said that the stress acts parallel or perpendicular to the *force*, rather than to an *area*. This reveals that students did not understand the connection between stress, force, and area. If this had been a multiple-choice question with options of parallel and perpendicular, it is likely a vast majority of students would have gotten it correct and this misconception would not have been revealed. This is one example of many similar misconceptions drawn out in the short answer questions.

Using ChatGPT

Using ChatGPT effectively took a lot of trial and error. Being as explicit as possible in prompts and not giving it room to make any judgement calls yielded the most accurate results. It is important to use prompts with clear criteria and indicate the exact word or phrase must be present. Otherwise, it made inaccurate interpretations of student responses. Prompting with these stringent instructions resulted in many responses that indicated the learning goal was either met or almost met not being identified as such, but it also did not result in any false positives. Even with a stringent prompt, it is important to review what ChatGPT provides for accuracy. With some practice, it can be used quickly and reliably to categorize student responses where key words or phrases can be identified.

Using warm-ups in class

Using JiTT requires a change in how instructors think about teaching and about class time [3]. This was true for this author as well. In previous semesters teaching without JiTT, the author automatically assumed that students were not coming to class prepared. Therefore every definition, concept, and application was detailed as if the students were being introduced to it for the first time. During the design phase of the warm-ups, it became clear that if students were expected to use the warm-ups effectively, the instructor needed to hold them accountable by not reviewing every concept in class as if they had never seen it before.

There is also a risk in not spending time on concepts that students could use more support and practice with, even if they did read about it in the textbook. The feedback loop constructed by the warm-ups closed this gap. The level of student understanding was apparent in their responses, so it was known exactly what needed to be reviewed and practiced in class. Ending every warm-up with the “muddiest” point question was also invaluable. There were many instances in which students answered a question correctly, but indicated they were not confident in their answer in the muddiest point question. This lent further insight into what needed to be touched on in class to best support their learning. Another interesting insight that came from the muddiest point questions was that usually the aspect of the reading that one set of students found the most confusing, another set of found the most interesting.

When most students demonstrated they had met a learning goal, the class content previously used to introduce a topic was replaced with the students’ own responses to the warm-up. Examples include “Why do you think an engineer cares about stress?” or “What benefit do you think having a beam made of more than one material provides? Can you think of any examples of beams made of two or more materials?” Their responses led to a rich discussion in class.

Future Work

For the most part in this study, the correct answers to warm-up questions were not given to students until they came to class. Future implementations of JiTT could investigate the benefit of providing instantaneous feedback to students, either immediately after or while they complete the warm-up assignment. There is ample evidence that timely feedback supports student learning [9]. This could assuage the frustrations of the student who found themselves having to unlearn concepts from the reading and warm-up, quoted previously.

The impact of the warm-up assignments on student's conceptual understanding of the material could also be measured. Common means of assessing conceptual understanding are concept maps [4], concept inventories and ConcepTests [10].

Conclusion

Implementing JiTT certainly benefitted the students in this study. It helped them stay on top of the material, come to class prepared to learn, and helped them see how useful their textbooks are. It also acted as a catalyst for the instructor to think creatively about how to best use class time to support student learning. Students asked deeper questions in class and showed interest in why engineers care about these concepts. Their perception of the assignments was overwhelmingly positive. Short answer and multiple-choice type questions were moderately successful at helping students demonstrate mastery of low-level learning goals, but the most important take-away from each assignment was that the instructor knew exactly where the students' level of knowledge was. Class time could then be tailored to address what the students needed.

Acknowledgments

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Appendix

Example of ChatGPT's summary of a "muddiest" point question

Here's a summary of what the students found confusing and interesting in the second set of responses:

Confusing:

1. Clarifying torsion conventions on an x-y axis.
2. The complexity of torque, including normal forces and the presence of a normal force inside the bar.
3. Relating different gear ratios to differences in torque and torsion.
4. Calculating torque for hollow cylinders and choosing the correct formula.
5. Managing the large number of variables and their similar meanings.
6. Equations related to torque and their connection to torsion.
7. Units and reconciling them in the context of torque calculations.
8. The "double arrow" method for determining torsion sign convention.
9. Specific examples for each equation and when to use different "J" equations.
10. Understanding torsional shear stress.
11. Uncertainty about the correctness of their answers.
12. The meaning of the rho variable in the equation relating torque to shear stress.
13. How to solve for torque when it's not perpendicular to its axis of spin.
14. Handling hollow sections in problem-solving.
15. The difference between torque and torsion.
16. The physical representation and derivation of larger equations.
17. Understanding polar coordinates.

18. Differentiating between Ri and Ro when calculating torque and polar moment.
19. The impact of torsional shear stress on multiple planes.
20. Why bones break easily under applied torque.
21. The connection between units in different calculations.

Interesting:

1. The realization that nothing is as simple as "just torque" and that normal forces are involved.
2. The engaging Lego video explaining mathematical and engineering concepts.
3. The focus on torsion in gears and its practical applications.
4. The concept of stresses on oblique planes, including both normal and shear stress.
5. The power of gear ratios and practical applications, as demonstrated in videos.
6. The significance of the polar moment of inertia in designing objects.
7. Shear stress on cross-sectional and longitudinal surfaces.
8. The ease of bone breakage under applied torque in arm wrestling scenarios.