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Sticking Points: Reasons Why Civil Engineering Students Make Errors Solving Engineering Mechanics Problems

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Abstract

A mechanics diagnostic exam has been administered to junior and senior civil engineering students at the U.S. Military Academy at West Point since 2018, to test the fundamental mechanics concepts critical to upper-level civil engineering courses. A previous study revealed a student's ability to correctly identify and classify engineering problems as crucial to success on mechanics problems. If a student did not properly classify the mechanics problem asked on the diagnostic exam, the student would tend to make major conceptual errors. However, for students who correctly classified the mechanics problem, it was difficult to determine if incorrect solutions were attributable to math errors or conceptual misunderstandings. For this study, students were asked to solve a truss analysis problem similar to the one on the mechanics diagnostic exam, while an instructor observed the students' problem-solving process at a chalkboard. After completion of the problem, each student participated in an interactive reflection session. Using a consistent assessment format, instructors were able to identify student hesitations and conflicts while solving the problem and determine whether they were a result of conceptual or non-conceptual errors. Following the assessment, the researchers asked each study participant questions to prompt reflection on why certain errors were made. This paper summarizes the assessment and reflection procedure used, a small sample of students' performance on a traditional paper-based assessment compared to the interview assessment, and the reasons for errors. Recommendations for future research and improving course delivery to prevent misconceptions are provided.

Introduction

Strong knowledge of fundamental mechanics is essential for success in undergraduate engineering curricula. Specifically for civil engineering students, statics and mechanics of materials knowledge are essential for success in advanced analysis and design courses. A previous study developed a diagnostic exam to assess the retention of mechanics knowledge [1]. Two different exams were administered to third-year and fourth-year students, respectively, for the past five years. The exam tested ten different topics from statics and mechanics of materials, including truss analysis, indeterminate axially loaded members, shear and moment diagrams, stress and strain, beam deflections, indeterminate beam analysis, and combined loading. The historical performance of students on the mechanics diagnostic exam was used to measure retention of core mechanics concepts, help students identify weak areas to aid in their preparation for the Fundamentals of Engineering (FE) Exam, and assess the impact of changes made to the curriculum year to year.

The results of the diagnostic exam showed integrating concepts into multiple courses improved performance, identifying the type of problem was essential for students to be successful, and instructors had a difficult time assessing student conceptual understanding when students had multiple compounding errors [1]. The latter conclusion was the most significant. To improve student performance, it is necessary to understand why the errors occurred. Unless an instructor identified whether an error was due to a simple calculation mistake or a conceptual gap in knowledge, the instructor was unable to assess a student's mastery level. Bruhl et al. posed the question, "Why do students make the errors identified?" [1] The study presented in this paper aimed to answer this question by conducting an instructor-observed assessment of a student's problem-solving process for a basic mechanics problem, coupled with an interactive reflection. The research question this study sought to answer was: can instructors assess student mastery of mechanics concepts more accurately when observing a student problem-solving process followed by an oral reflection session?

To answer this question, the authors developed a framework for an in-person instructor-observed assessment and reflection session for engineering students. The results of the student assessments were compared to a traditional paper-based mechanics diagnostic exam. The types of errors made by each student were identified and categorized as non-conceptual, minor execution, and major execution. The assessment also determined whether a student identified an efficient solution or took unnecessary steps in solving the problem. After a student completed the problem, an instructor interviewed the student to encourage reflection on, and explanation of, their problem-solving process. The student explanations provided the instructors with additional information to help identify the sources of any errors. The assessment and reflection framework presented in this study may be used by follow-on researchers to assess student mastery in engineering courses.

Motivation

Retention of fundamental concepts is one of the greatest pedagogical challenges facing engineering educators. When students lack the prerequisite knowledge needed for advanced courses, it can have detrimental impacts on the pace of the course and student requirements. Many researchers have conducted studies to measure student retention of key concepts from basic engineering courses [2], [3]. Studies have proposed curriculum changes to improve student retention. Some changes were as simple as adding review problems to homework assignments [4]. Other institutions developed cross-department integration and sequencing of non-engineering courses such as math and physics with fundamental mechanics courses [5]. Researchers found active learning environments, recitation periods, and laboratory sessions increased retention of or connection to key course concepts [6], [7], [8], [9]. Improving students' conceptual understanding significantly impacted student retention [10].

Researchers have developed concept inventories to improve students' conceptual knowledge of mechanics topics [11], [12]. More recently researchers have developed targeted problems that allow them to identify the most common sources of error or misconceptions observed [13], [14], [15], [16]. Each of these researchers categorized the types of errors into buckets such as preconceived misunderstanding, incomplete understanding, or incorrect understanding [14], factual, procedural, or conceptual [15], and conceptual versus non-conceptual [16].

An important gap in the research is the ability to identify why students make certain errors. Only a few researchers have attempted to answer this question for engineering mechanics. Papadopoulos, Rahman, and Bostwick determined that even when students get the correct answer, they usually miss a critical element of the problem [17]. They found these missed elements are due to an inability to think critically. Students' struggles were due to specific teaching practices, course structure or inconsistencies with the textbook, which do not promote critical thinking. Barry, Graves and Klosky identified that time was the most significant factor affecting retention of mechanics concepts, specifically the length of time removed from the course material over summer break [18]. The study presented in this paper investigated why students make errors in mechanics problems through an in-person, one-on-one assessment followed by a reflection session. This form of oral assessment allowed instructors to determine how and why students made specific errors within their problem-solving process. Metacognitive learning and study strategies, including reflections, self-assessment, self-questioning, and think-aloud strategies resulted in superior student learning and retention of material [19].

Previous Research

Joughin identified that all effective oral assessments must include the following: primary content, interaction, authenticity, structure, examiners, and orality [20]. Jensen discusses the format for an oral assessment that has been implemented for over 20 years [21]. Students get 60 minutes to prepare their responses and then 20 minutes to present their work. They are allowed to work on a blackboard or whiteboard. The topic students are assessed on is selected from 20 course topics. The instructor team administered assessments for 40 students over two days, which was equated to a similar workload of grading written exams. The researchers found it was relatively easy to spot "imposters" during the oral assessment. Previous research has found that oral assessments improve student performance but may increase anxiety [22], [23], [24]. The increase in anxiety was attributed to an increase in the amount of preparation before the assessment. One of the greatest benefits of oral assessments has been the dedicated opportunity for students to reflect on their knowledge and understanding of course material [25], [26]. Interactive oral assessments allow for dialog between students and instructors to promote reflection by students, identify sticking points within the curriculum, and provide instructors with greater assurance of the quality of students' learning [25], [27].

Recently, a research group from the University of California San Diego conducted an extensive project sponsored by the National Science Foundation to investigate a variety of educational impacts oral examinations can have on student performance [28]. Oral examinations were implemented in six electrical and mechanical engineering courses. The motivation for the research was to improve student engagement and maintain academic security during remote classes as a result of the COVID-19 pandemic [29]. The authors wanted to implement an assessment that could also help promote conceptual mastery. With enrollments as high as 200 students, the institution employed teaching assistants and tutors to administer the examinations. The authors explored the implementation of peer oral assessments to improve the efficiency of using oral assessments in large enrollment courses [30]. A secondary benefit of the oral examinations was student rapport with their instructor teams. The authors also found that student performance on an oral midterm examination was a better predictor of final exam performance than a written midterm examination [31]. The authors concluded that oral exam performance may be used to assess retention. The oral examinations promoted reflection, improved student performance and technical communication skills, increased their motivation to learn, and provided students with real-time feedback [28], [32], [33].

Douglas and Knighten conducted a similar study to the one presented in this paper, where they administered oral quizzes to students on engineering mechanics concepts [34]. Students were asked to solve an FE-style question. They were given 1-2 minutes to interpret the question, develop a strategy, and ask any questions. Students were then encouraged to talk during the quiz and explain each step. Instructors provided reassurance during the student problem-solving process and would correct errors but would wait briefly to see if the students were able to catch their own errors. Some students used the oral quiz as an opportunity to ask the instructor questions and to clarify points of confusion as a form of mandatory office hours. After the quiz ended, the instructor would ask a follow-up question to assess conceptual understanding. The researchers developed a rubric for the oral quizzes that was broken down into vocabulary/terminology, content, solution, organization, effort, and motivation. The researchers found that the assessment improved technical communication skills, performance compared to written quizzes, and student study habits.

Objectives

The purpose of the study described in this paper was to develop a framework for an in-person assessment and reflection session, which could be readily adopted by higher education instructors. The objectives of the study were:

1. Determine why students make certain errors.
2. Evaluate mastery of a student's problem-solving process.
3. Create an environment for student reflection.

The first objective built off previous research using a similar diagnostic exam designed to test fundamental concepts and measure retention [1]. The objective is not just to identify the type of error, but to determine why students make these common errors and whether it is related to retention, aspects of the curriculum, or misconceptions. These observations of why the students were making certain errors helped achieve the second objective of allowing an instructor to evaluate mastery of the student's knowledge as opposed to just the accuracy of their final solution. The third objective was to improve students' metacognition, by providing them an opportunity to reflect after completion of the assessment.

Methodology

At the start of the Fall Semester, the research team administered the mechanics diagnostic exams described in Bruhl et al. to 12 third-year and 31 fourth-year civil engineering students [1]. The diagnostic exam was offered as an optional activity for extra credit. The exams were graded for correctness and characterized the students' errors using three error categories: non-conceptual, minor execution, and major conceptual as was done in previous research. Immediately following the exam, students were invited to review their work with a faculty member.

The research team reviewed the performance of all 43 students on the diagnostic exam truss problem shown in Figure 1. The third-year and fourth-year students were given different problems as shown in Figures 1a and 1b, respectively. Based on the solution accuracy, students were grouped into three levels: proficient, marginally proficient, and not proficient.

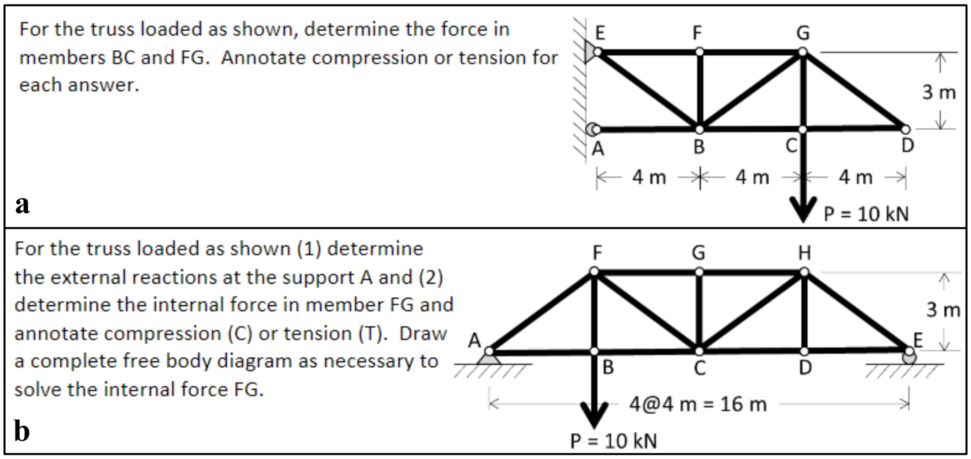


Figure 1: Diagnostic exam truss problems: a) third-year question, b) fourth-year question.

The research team recruited students from each level to participate in an instructor-observed problem-solving session. Unlike a traditional oral assessment, the instructor-observed problem-solving session was not meant to be interactive before the reflection portion. To start the problem-solving session, members of the research team read a standardized welcome brief and set of instructions to each student, provided in Appendix A. Prior to beginning the assessment, the instructor asked the student if they had any questions. After beginning the assessment, however, the students were not allowed to ask any questions. The instructor-observed problem-solving session included many of the required aspects of an oral assessment. The students were not aware of what mechanics topic they would be assessed on during the session. The students solved a basic truss analysis problem, which included drawing a free body diagram, verifying equilibrium, and solving for internal forces, shown in Figure 2. The students solved the problem using a chalkboard and calculator in front of one or two members of the research team. The students were not required to speak aloud during the assessment, and no time limit was enforced.

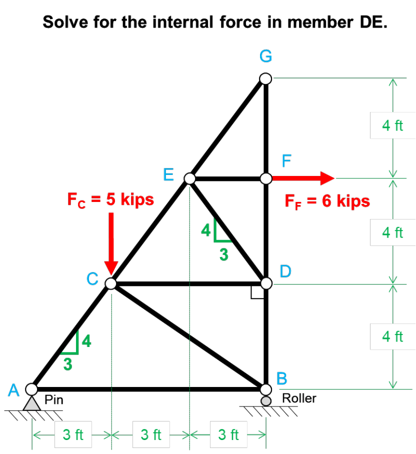


Figure 2: Problem used during instructor-observed problem-solving session.

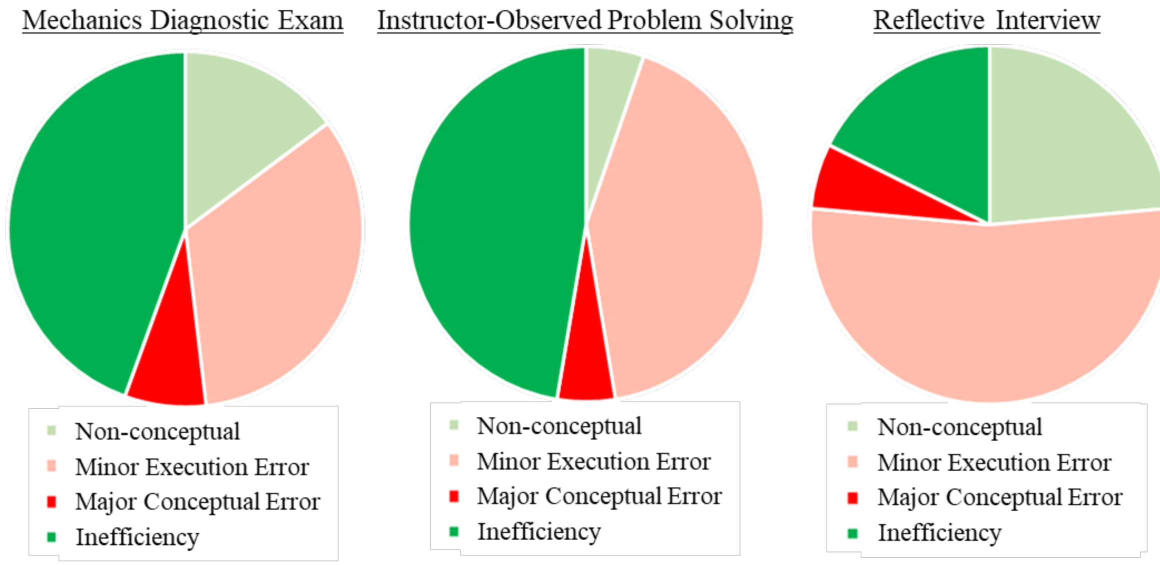
After each student completed their attempt to solve the problem, the members of the research team and the students participated in an interactive reflection session to discuss the students' problem-solving process and clarify any steps taken. The interview form shown in Appendix B outlines the standard procedure used during the reflection session. The students first took a moment to review their work. The instructors asked the students to rate their level of confidence on a scale from 1 to 5. In addition to providing greater insight for the research team, this sequence of questions created an environment to encourage the students to reflect on their work. The students were asked to discuss areas where they were uncertain and to identify any errors found in their problem-solving process. Following this self-reflection opportunity, the research team began to ask leading questions to evaluate the efficiency of the students' problem-solving process by asking the students to investigate alternative approaches to solve the problem. The instructor then provided the student with feedback on their approach to the problem and discussed their assessment of the student's performance. Following the interactive session, the students completed a paper survey to assess what learning activities most contributed to their ability to solve the problem, provided in Appendix C. The sessions were video recorded to capture the students' work, comments, and answers to the reflection questions.

Results and Discussion

Ten students completed the instructor-observed problem-solving and reflection session during the 2024 academic year including four third-year and six fourth-year students. Each of these students also took the paper-based mechanics diagnostic exam. Based on their performance on the mechanics diagnostic exam, the researchers categorized four students as not proficient, four students as marginally proficient, and two students as proficient. The types of errors observed on the paper-based mechanics diagnostic exam are shown in Figure 3(a). In the previous study, the types of errors included only non-conceptual, minor execution, and major conceptual errors. For this study, however, a fourth category was included for inefficiency. The inefficiency category assessed whether a student used the most efficient method to solve the truss problem. A correct answer computed using the most efficient method demonstrated complete mastery of the concept. Figure 3(b) shows a breakdown of the errors by type made during the instructor-observed problem-solving session.

On both the mechanics diagnostic exam and the instructor-observed problem-solving session, three students (30%) attempted the problem using the most efficient method. However, only one student used the most efficient method during both assessments, though that student made minor execution errors on both assessments. Thus, five students (50%) used the most efficient problem-solving process during either the paper-based or instructor-observed assessment. On each assessment, one student (10%) solved the problem correctly demonstrating complete mastery of the concept, but the student who solved the problem correctly and efficiently on the written mechanics diagnostic exam was not the same student who solved the problem correctly and efficiently in the instructor-observed problem-solving session.

Figure 3(c) shows the errors by type made during the reflective interview. The instructors observed the greatest percentage of inefficiencies followed closely behind by minor execution errors. When the students reflected on their work and were asked to identify their errors, nine out of ten students were able to correctly identify at least one of their errors. Nonetheless, the students incorrectly identified a disproportionate amount of minor execution errors and struggled to identify the inefficiencies in their process or major conceptual errors. Only one student was able to reflect on their work and identify the most efficient method. This student was the same one who solved the problem correctly using the most efficient method on the mechanics diagnostic exam.



(a) (b) (c)

Figure 3: Comparison of Error types for truss analysis problems – (a) Mechanics diagnostic exam; (b) Instructor-observed problem-solving; (c) Reflective Interview

As seen in Table 1, outside of inefficiency, rigid body equilibrium mistakes were the most common error on both the mechanics diagnostic exam and the instructor-observed problem-solving. More specifically the errors the students made were either an inability to solve for the dimensional (*x* and *y*) components of an internal resultant force or to properly solve for equilibrium of moments for their free-body diagram. It is important to note that on the mechanics diagnostic exam, 50% of the participants completely avoided equilibrium of moments for the truss problem by using the method of joints multiple times as opposed to the method of sections. This approach was not commonly observed in the previous study [1]. The researchers believe this result may be attributable to a transition made in the Fundamentals of Engineering Mechanics and Design Course during the 2022 academic year from a scalar-based statics curriculum to a vector-based statics curriculum. When responding to the question "What were you most uncomfortable with while solving the problem?", 50% of the students acknowledged they were most uncomfortable with summing moments. One student even stated they started solving for the sum of the moments using the vector method, but after struggling to set up the vector cross-product, decided to switch to the scalar method because it was easier. The in-person instructor-observed problem-solving assessment coupled with the reflective interview allowed the instructors to observe students' processes and hesitations. These observations aided in the instructor's ability to identify the type of error.

Table 1 Errors on Truss Analysis Problem by Assessment Type

Error Description		Mechanics Diagnostic	Instructor Observed	Reflective Interview
Non-Conceptual Errors	Calculation or transcription	1	0	0
	Trigonometry error	1	1	3
	Final Answer expressed incorrectly	2	2	1
Minor Execution Errors	T/C wrong or wrong reaction direction	0	0	1
	Rigid body equilibrium mistake	3	3	4
	Error on joint/section FBD (truss cut analysis error)	1	1	0
	Negative sign substitution error	0	2	2
	Incomplete solution, missing answer for one member force	0	0	0
	Missed zero force member	3	0	2
Major Conceptual Errors	Major FBD errors	1	0	0
	Essentially no clue	1	1	1
Inefficiencies	Solved for external reactions	4	3	0
	Incorrect cut	2	1	0
	Summed moment about different point	6	6	3
	TOTAL ERRORS	25	20	17

Figure 5 shows the total number of inefficiencies found through the paper-based mechanics diagnostic exam, during the instructor-observed problem-solving session, and by the students during the reflection period. The greatest number of inefficiencies in solving the truss analysis problem was completing the equilibrium of moments about an inefficient point. Six of the students computed the equilibrium of moments about an inefficient point. By summing for moments about an inefficient point, the students had to include more than one unknown internal force. This approach added a step to their problem-solving process. During the reflection process, three of these students (50%) were able to identify there was a more efficient point. Two of the students not able to identify that they computed the equilibrium of moments about an inefficient point also made an incorrect cut. Eight (80%) of the students were able to identify that a section cut through the member of interest was the most efficient method. About one-third of the students on both the mechanics diagnostic exam and instructor-observed problem-solving session solved the external reactions as their first step. When reflecting on their completed work, these students were not able to identify a more efficient method. This finding may be attributed to the standardized problem-solving approach that is taught in the Fundamentals of Engineering Mechanics and Design course, where students are encouraged to do the following in sequential order: draw a free-body diagram, solve for external reactions, make a truss cut, and solve for internal forces.

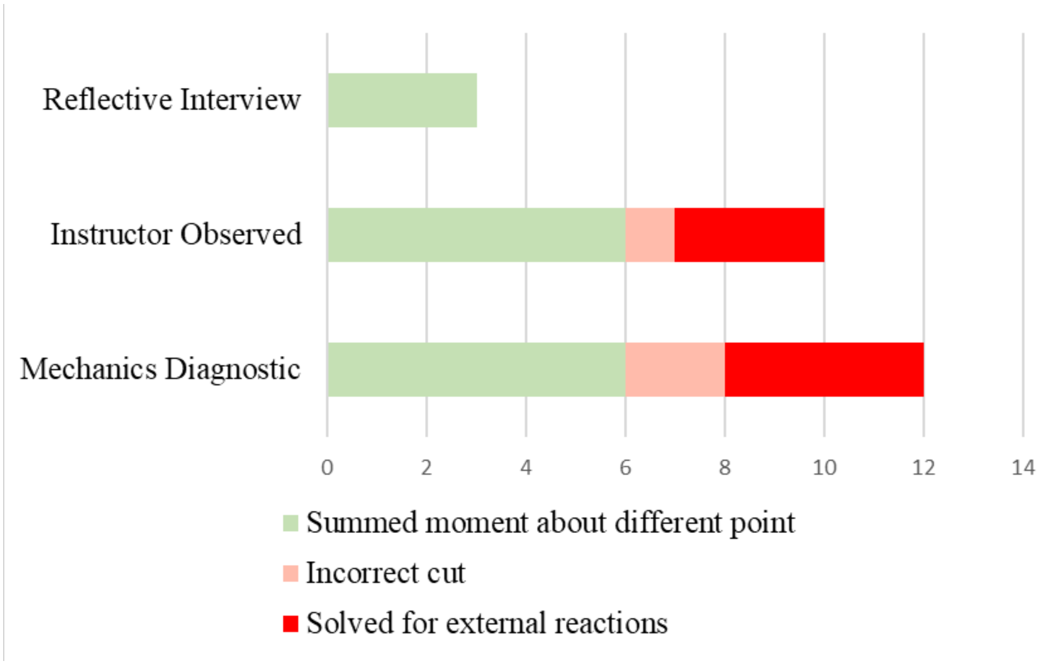


Figure 5. Summary of Inefficiency Types by Assessment Method

Previous research revealed one of the biggest challenges for students was to correctly identify the type of problem they were being asked to solve [1]. While this finding was primarily observed in statically indeterminate problems, the current study observed that some students struggled with correctly identifying a truss analysis problem as well. During the instructor-observed problem-solving sessions, nine out of ten students were able to identify the problem as a truss analysis and correctly executed truss cuts to solve for the internal force with only minor execution errors or inefficiencies. Only one student made an incorrect cut, which was classified as a major execution error. The research team evaluated the students' work as essentially having no clear understanding of how to obtain a solution. During the reflective interview, the student revealed they did not know if the problem was a truss or a frame. The student was able to describe the correct process to the instructor, indicating that if they had correctly identified the type of problem, they may have been able to demonstrate greater proficiency.

After the instructor-observed problem-solving session, each student was asked "What would have helped you solve the problem?" Five of the ten said they would have benefited from more recent practice or access to their old notes. This feedback suggests a lack of confidence in their retention of the course material. However, three of the five were able to correctly solve the problem. One of the three rated their confidence as 2 out of 5. This lack of confidence translated to major conceptual misunderstandings when they incorrectly identified two different "errors" during the reflective interview, which were not actually errors. This discussion allowed the researchers to assess the student's mastery level as opposed to just accuracy.

Following the reflection session, students were asked to review ten teaching methods and learning activities, rank-ordering them from most useful (1) to least useful (10) in understanding the concepts required to solve the problem. Activities associated with in-person instruction (instructor lectures, board notes, in-class demonstrations, and instructor-worked example problems) were generally perceived as the most useful activities, scoring an average rank of 3.1. Activities related to problem-solving (instructor-led, collaborative among students, and individual) scored an average rank of 5.3, indicating moderate usefulness. Instructor-led problem solving scored notably higher, with an average rank of 2.9. Other activities (reviewing instructor solutions, reading the textbook, and consulting online videos and other resources) were perceived as the least helpful, ranking 7.9 on average.

During the reflective interviews, many students remarked on the nature of in-person problem-solving in front of an instructor, noting differences in performance pressure compared to taking a paper-based exam. Students perceived the event as "stressful" and "anxiety-inducing," feeling they "couldn't hide" during in-person problem-solving while they could during the paper-based exam. With no time limit on the assessment, students ranged from 7 minutes, for a student who rated their confidence as a 4 out of 5, to 26 minutes for a student who rated their confidence as a 1 out of 5. Even a single problem solved with no time limit was sufficient to elicit these responses in the majority of students who participated in the study. One student noted that the one-on-one dynamic of the assessment was additional motivation to do well on the problem. This observation matched other literature, which demonstrated that in-person oral examinations were more stressful, but it was easier to identify imposters [21], [22]. However, the students also appreciated the opportunity to have a one-on-one review with an instructor. Five of the ten students acknowledged it was a good review opportunity of fundamental mechanics concepts, which helped them identify their own shortcomings and prepare them for future courses or the FE Exam. Three other students mentioned it was a good experience for their oral technical communication skills by explaining their process using correct terminology.

Conclusions

The study presented in this paper investigated the design and implementation of an instructor-observed problem-solving session followed by an interactive reflective interview. The authors presented the results from a small sample size of 10 students to determine the feasibility of the assessment format. The most common errors made by students on truss analysis problems were minor execution errors; more specifically, rigid body equilibrium and trigonometry errors. Additionally, the researchers identified that even if a student solved a truss problem correctly, it is unlikely they select the most efficient method. This inefficiency was the result of uncertainty with rigid body equilibrium in selecting a point to sum moments.

The student responses to the reflective interview allowed the instructors to understand why students made certain errors or why they tended towards more inefficient approaches to solving the problem. Students expressed discomfort with trigonometry, specifically resolving an internal force into its directional (*x* and *y*) components. Some students stated they understood the need to use the method of sections but avoided solving for rigid body equilibrium of moments due to their lack of retention of the concept. If the students did solve for rigid body equilibrium, most used a scalar method to calculate moments, even though some students thought the vector method may have been more efficient. The observations of the instructor during the problem-solving process, coupled with the student responses during the reflective interview, provide greater insight into student mastery of concepts than the written test alone.

While students expressed solving a problem one-on-one with an instructor increased their level of stress, the students also recognized the benefits of completing the instructor-observed problem-solving session and reflective interview. The benefits included additional time with the instructor to review previous concepts, practice using technical communication skills, and identifying areas of weaknesses in preparation for the FE Exam. While the students were not able to identify all errors during the interactive review session, each student identified at least one error in their work.

Overall, with a limited sample size, the instructor-observed problem-solving session coupled with an interactive reflective interview was shown to be an effective assessment technique for evaluating students' comprehension of fundamental concepts. Future research will investigate using the methodology for an entire course as an assessment method with a larger sample size to draw more statistically significant conclusions. The authors will also compare the results of their instructor-observed assessments to students' GPA and FEE pass rate.

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References

[1] J. C. Bruhl, J. Hanus, K. McMullen, and B. Rocha, "Identifying Sticking Points: Common Mechanics Errors Made by Civil Engineering Students," in *ASEE Annual Conference & Exposition*, Minneapolis, MN: American Society of Engineering Education, Jun. 2022.

[2] J. Direnga, B. Presentati, D. Timmermann, A. Brose, and C. Kautz, "Does it stick?- Investigating long-term retention of conceptual knowledge in mechanics instruction," in *ASEE Annual Conference & Exposition*, Seattle, WA: American Society of Engineering Education, Jun. 2015.

[3] W. Graves, Y. Chun, J. Klosky, and B. Barry, "Will They Remember? Measured Knowledge Retention Across Statics and Solid Mechanics," in *ASEE Annual Conference & Exposition*, Seattle, WA: American Society of Engineering Education, Jun. 2015.

[4] J. Bruhl, K. Arnett, and J. Hanus, “Strengthening Connections: The Effectiveness of Review Problems on Student Retention of Mechanics Concepts,” in *ASEE Annual Conference & Exposition*, Virtual: American Society of Engineering Education, Jul. 2021.

[5] K. Wingate, A. Ferri, and K. Feigh, “The Impact of the Physics, Statics, and Mechanics Sequence on Student Retention and Performance in Mechanical Engineering,” in *ASEE Annual Conference & Exposition*, Salt Lake City, UT: American Society of Engineering Education, Jun. 2018.

[6] M. Hoit and M. Ohland, “The Impact of a Discipline-Based Introduction to Engineering Course on Improving Retention,” *Journal of Engineering Education*, vol. 87, no. 1, pp. 79–85, Jan. 1998, doi: 10.1002/j.2168-9830.1998.tb00325.x.

[7] B. Wheatley, T. Donahue, and K. Catton, “An Active Learning Environment to Improve First-Year Mechanical Engi-neering Retention Rates and Software Skills,” in *ASEE Annual Conference & Exposition*, Columbus, OH: American Society of Engineering Education, Jun. 2017.

[8] M. Saad, T. Abu-Lebdeh, D. Pai, and C. Waters, “Recitation in Core Engineering Mechanics Courses: Implications for Retention and Student Performance,” in *ASEE Annual Conference & Exposition*, Honolulu, HI: American Society of Engineering Education, Jun. 2007.

[9] G. Liu and N. Fang, “The effects of enhanced hands-on experimentation on correcting student misconceptions about work and energy in engineering mechanics,” *Research in Science and Technological Education*, vol. 41, no. 2, pp. 462–481, Jul. 2023, doi: 10.1080/02635143.2021.1909555.

[10] G. Chauda and G. Recktenwald, “Effect of a Concept Review Intervention on the Student’s Knowledge Retention and Demonstration of Pre-requisite Fundamental Concepts,” in *ASEE Annual Conference & Exposition*, Virtual: American Society of Engineering Education, Jul. 2021.

[11] P. Steif, “Initial Data from a Statics Concept Inventory,” in *ASEE Annual Conference & Exposition*, Salt Lake City, UT: American Society of Engineering Education, Jun. 2004.

[12] J. Richardson, P. Steif, J. Morgan, and J. Dantzler, “Development of a concept inventory for strength of materials,” in *Proceedings - Frontiers in Education Conference, FIE*, Boulder, CO: Institute of Electrical and Electronics Engineers Inc., Nov. 2003. doi: 10.1109/FIE.2003.1263342.

[13] R. Streveler *et al.*, “Identifying and Investigating Difficult Concepts in Engineering Mechanics and Electric Circuits,” in *ASEE Annual Conference & Exposition*, Chicago, IL: American Society of Engineering Education, Jun. 2006.

[14] G. Liu and N. Fang, “Student Misconceptions about Force and Acceleration in Physics and Engineering Mechanics Education,” *International Journal of Engineering Education*, vol. 32, no. 1, Aug. 2016.

[15] T. Goldfinch, A. Carew, and T. Mccarthy, “A Knowledge Framework for Analysis of Engineering Mechanics Exams,” in *Proceedings of the Research in Engineering Education Symposium*, Palm Cove, QLD: REES, 2009.

[16] S. Gross and D. Dinehart, “Identification of Common Student Errors in Solving Fundamental Mechanics Problems,” in *ASEE Annual Conference & Exposition*, San Antonio, TX: American Society of Engineering Education, Jun. 2012.

[17] C. Papadopoulos, A. Rahman, and J. Bostwick, “Assessing Critical Thinking in Mechanics in Engineering Education,” in *ASEE Annual Conference & Exposition*, Chicago, IL: American Society of Engineering Education, Jun. 2006.

[18] B. E. Barry, W. Graves, and L. Klosky, “Knowledge Decay in an Engineering Mechanics Sequence,” *Journal of Professional Issues in Engineering Education and Practice*, vol. 143, no. 3, Nov. 2016, doi: 10.1061/(ASCE)EI.

[19] H. Hartman, “Developing Students’ Metacognitive Knowledge and Skills,” *Metacognition in Learning and Instruction: Theory, Research, and Practice.* , pp. 33–68, Feb. 2001, doi: 10.1007/978-94-017-2243-8_3.

[20] G. Joughin, “Dimensions of oral assessment,” *Assess Eval High Educ*, vol. 23, no. 4, pp. 367–378, 1998, doi: 10.1080/0260293980230404.

[21] B. Jensen, “Oral assessment in engineering education,” *International Journal of Electrical Engineering Education*, vol. 47, no. 4, 2010.

[22] M. Huxham, F. Campbell, and J. Westwood, “Oral versus written assessments: A test of student performance and attitudes,” *Assess Eval High Educ*, vol. 37, no. 1, pp. 125–136, Feb. 2012, doi: 10.1080/02602938.2010.515012.

[23] K. Rouser, “Oral Assessments of Student Learning in Undergraduate Aerospace Propulsion and Power Courses,” *ASME Journal of Engineering for Gas Turbines and Power*, vol. 139, no. 12, Dec. 2017, doi: 10.1115/1.4037577.

[24] K. Ward and Y. Lou, “Oral Formative Assessment as a Means to Increasing Total Learning and Engagement in an Engineering University Classroom,” in *ASEE Annual Conference and Exposition*, Virtual: American Society of Engineering Education, Jun. 2020.

[25] A. Karltun and J. Karltun, “Interactive Oral Assessment Supporting Active Learning,” in *Proceedings of the 10th International CDIO Conference*, Barcelona, Spain, Jun. 2014.

[26] S. Nikolic, D. Stirling, and M. Ros, “Formative assessment to develop oral communication competency using YouTube: self- and peer assessment in engineering,” *European Journal of Engineering Education*, vol. 43, no. 4, pp. 538–551, Jul. 2018, doi: 10.1080/03043797.2017.1298569.

[27] S. Shaeri, D. Logan, and A. Krautloher, “Evaluating Competency Development Using Interactive Oral Assessments,” in *Research in Engineering Education Symposium &*

Australasian Association for Engineering Education Conference, Perth, WA, Dec. 2021. doi: 10.3316/informit.345915443844801.

[28] S. Baghdadchi, H. Qi, M. Lubarda, A. Phan, N. Delson, and C. Sandoval, "Student perceptions of oral exams in undergraduate engineering classes and implications for effective oral exam design," in *ASEE Annual Conference and Exposition*, Minneapolis, MN: American Society of Engineering Education, Jun. 2022.

[29] M. Lubarda *et al.*, "Oral exams for large-enrollment engineering courses to promote academic integrity and student engagement during remote instruction," in *Proceedings - Frontiers in Education Conference, FIE*, Institute of Electrical and Electronics Engineers Inc., 2021. doi: 10.1109/FIE49875.2021.9637124.

[30] M. Lubarda *et al.*, "Peer oral exams: A learner-centered authentic assessment approach scalable to large classes," in *ASEE Annual Conference and Exposition*, Baltimore, MD: American Society of Engineering Education, Jun. 2023.

[31] M. Kim, C. Pilegard, M. Lubarda, S. Baghdadchi, A. Phan, and H. Qi, "Midterm oral exams add value as a predictor of final written exam performance in engineering classes: A multiple regression analysis," in *ASEE Annual Conference and Exposition*, Minneapolis, MN: American Society of Engineering Education, Jun. 2022. [Online]. Available: www.slayte.com

[32] C. Schurgers *et al.*, "Oral Assessments as an Early Intervention Strategy," in *ASEE Annual Conference and Exposition*, Baltimore, MD: American Society of Engineering Education, Jun. 2023.

[33] N. Delson *et al.*, "Can Oral Exams Increase Student Performance and Motivation?," in *ASEE Annual Conference and Exposition*, Minneapolis, MN: American Society of Engineering Education, Jun. 2022. [Online]. Available: www.slayte.com

[34] J. Douglas and R. Knighten, "Using Oral Quizzes in an Engineering Mechanics Course," in *ASEE Annual Conference and Exposition*, Iowa City, IA: American Society of Engineering Education, Oct. 2014.

Appendix A

Thank you for your willingness to participate in this study. Shortly we are going to ask you to solve a mechanics problem on the blackboard. Your work will be recorded as you solve the problem. Once you are complete solving the problem, I am going to ask you to answer a few questions about your problem-solving process. While you are not limited on time while solving the problem, you cannot ask any questions. At this time do you have any questions about the process? Go ahead and turn over the page to see the problem.

Appendix B

Mechanics Diagnostic Problem-Solving Session Procedure and Interview Form

Student: __________________________________ Date: ________________

Time taken to complete_____________ Correct Answer: YES Only minor errors NO

Notes:

Please take a second to review your solution, how confident are you, on a scale from 1 to 5, that you got the correct answer? _________________

Please explain why.

What were you most uncomfortable with while solving the problem?

What would have helped you solve the problem?

Would you have liked to ask a question while working on the problem?

Can you identify any errors in your solution?

a. If so, how would you correct them?
b. If so, how do you know it's an error?
c. If not, what gives you confidence that there are no errors?
d. If you identified an error during your process, how did you know it was an error?

How could you check your answer?

Please explain how you determined what was being asked in this problem and what it means.

Please explain your general strategy without going into great detail.

Describe how you chose to begin where you did.

a. If external reactions: “Do you think you need to solve for external reactions?”
    - If yes, why?
    - If no, what could you have done differently?
b. If zero force members: “Do you think you needed to identify zero force members?”
    - If yes, why?
    - If no, then why did you solve for them?
c. If cut, “please explain why you chose the first (equilibrium) equation that you did.”

Did you have an alternative approach that you would have liked to try? If so, why did you not try that approach?

After reviewing your solution,

a. Do you see a more efficient way to solve this problem?
b. Do you believe your process was the most efficient?

Discuss the Student's answer and their approach*

Do you think that participating in this interview was a valuable use of your time?

Would an oral exam fairly assess your knowledge on a mechanics or engineering topic?

Appendix C

Read the list of items below that may have contributed to you learning the concepts you used when solving the problem.
Please rank the items from 1 to 10 based on how much they contributed to helping you learn the concepts you used in solving this problem: #1 provided the greatest contribution and #10 contributed the least.
In-class experience:
___: Lectures from energetic instructors who are excited about the material.
___: Colorful board notes (5 colors of chalk, organized, neat, and thorough)
___: In-class demonstrations and hands-on learning activities
___: Example problems worked by the instructor.
___: Example problems worked independently or in small groups.

Out-of-class experience:
___: Problems worked independently.
___: Problems worked with fellow students.
___: Reviewing instructor solutions.
___: Reading the textbook or other course materials.
___: Other resources: online videos or websites

Please list any other resources or experiences that helped you understand the concepts you used in solving the problem.

____

____

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