

Board 303: Implementing Oral Exams in Engineering Classes to Positively Impact Students' Learning

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1. Introduction

Assessment is key to students' learning and effective educational improvement [1]. This is particularly critical in engineering, as a key objective of engineering education is teaching students how to apply scientific principles, how to reason about problems and how to think critically. Unfortunately, prior research has shown that many students often resort to memorizing procedures or processes, i.e., "plug and chug", rather than deeply understanding the core concepts and underlying scientific principles [2, 3]. They may be able to solve problems that are very similar to the ones shown to them by an instructor but cannot correctly reason about variations of these problems [4]. It is therefore important to be able to accurately test deeper conceptual understanding. It has been shown that the learning strategies and approaches that learners choose to adopt are driven by their anticipation of the type of exam. If an exam is procedural in nature, the learner will overvalue the pursuit of procedural knowledge over deep conceptual understanding [5]. Moreover, instructors may mistakenly assume that students understand concepts even if they simply are following a memorized procedure. As such, summative assessments (exams) that test concept mastery are essential to the learning process itself.

In most engineering courses in the United States, testing often relies on timed written examinations, which suffer from the aforementioned detrimental pull towards procedural knowledge [5]. However, there is an assessment strategy that is much better aligned with conceptual mastery: oral examinations. In general, the term oral assessment, also known as "viva voce", includes any form of dialogic test [6, 7, 8]. They have been found to be able to test higher level problem-solving and contextual thinking, by allowing an adaptive probing of the bounds of the learner's understanding [9, 10, 11, 12, 13]. Students can be asked about the "why", to think about alternative explanations and to explain their reasoning [14]. Joughin identifies three general classes of oral assessment [14]:

- (1) presentation, such as an in-class presentation on a topic or as part of a group project
- (2) application, such as the OSCE (Objective Structured Clinical Examination) in nursing/medicine involving simulated patient interaction
- (3) interrogation, such as within an undergraduate or graduate course where the student is quizzed by one or more examiners.

Our focus here is on the latter class: "interrogation" (although we will mostly try to avoid this terminology due to its negative connotations). Studies have shown that the strength of these oral assessments is in its ability "to distinguish superficial from real knowledge through in-depth questioning" [12]. In Bloom's taxonomy, learning objectives are separated into six levels of increasing depth/ complexity: knowledge, comprehension, application, analysis, synthesis and evaluation. It has been argued that oral examination is better suited than written tests to probe the higher levels of Bloom's taxonomy [15, 5, 10]. Such examination makes it possible to ask students "what if" and "why" as needed, to change the context on the go and prompt students to adapt their thinking, and to probe the edges of their knowledge.

In addition, the inherent adaptive nature of oral exams also carries another important benefit: if students anticipate getting probing questions, ones which get to the edges of their understanding, rather than involving the mere application of a predictable procedure, they will conclude that the best approach for scoring well is to develop a thorough understanding of the material [14]. The learner's interpretation and internalization of the learning outcomes is a key driver of their adoption of suitable learning strategies. Helping students realize that deep conceptual understanding is necessary to succeed at an exam is a key ingredient in steering them towards achieving these outcomes.

Integrating this powerful assessment strategy - oral exams is challenging in engineering courses. Various studies have noted that students report feeling increased anxiety around the use of oral exams [11, 13, 16, 17]. However, in most cases discomfort was seen to decrease with increased exposure to and familiarity with the test format. This is consistent with Hounsell et al. who suggest that students' anxiety is likely not inherent to the oral format itself, but may be a result of the novelty of this form of assessment [18]. Thus, student anxiety may be significantly mitigated by interventions designed to familiarize them with the oral exam format, such as practice opportunities or "dry-runs" [16]. Alternatively, Joughin suggests that some students may feel anxiety before an oral exam because they are aware that they have not deeply mastered the course material, and argues that in this case anxiety is productive in that it encourages students to modify their learning strategies to achieve deeper understanding [19].

Researchers have also noted challenges around grading oral assessments, including the potential for a lack of reliability between evaluators and the possible effect of implicit bias and subjective factors [20, 21, 22]. These concerns have led researchers to develop specific rubrics for scoring [23, 24], to utilize multiple simultaneous evaluators [25], and implement or suggest training for evaluators [11, 26]. However, more work is needed in developing and disseminating effective training materials for fairly scoring oral assessments in STEM classes, which will be elaborated on further in this proposal.

Finally, the most crucial barrier currently facing the use of oral exams in STEM is the issue of scalability to large classes. For small class sizes, researchers have shown that oral exams take only slightly more time for instructors to implement than written exams, with more hours spent on preparation and administration and less time on grading [27, 28]. However, as the number of students increases, the time required of an instructor to implement individual oral exams typically increases in proportion. Virtually all of the existing research has focused on relatively small classes (<50 students). In fact, of the studies cited above, only the two by Huxham et al. [11] and Grunwald et al. [29] deployed an oral exam in a STEM class with more than 100 students. The work of Huxham et al. focused on studying the efficacy of oral versus written exams and did not explicitly deal with issues of scale or considerations for wider adoption (in fact, in their 100 student course, students were split into those who did an oral exam and those who did a written one) [11]. Grunwald et al., implemented the oral follow-ups in a large computer science class with 600+ students, relying heavily on TAs [29]. They reported difficulties in both logistics and grading inconsistency, illustrating the need for training to be an integral part of the oral exam adoption strategy as in our proposal. In addition, their oral exams were very specifically designed as grading follow-ups to programming assignments and are harder to generalize to a more general STEM context.

Researchers have repeatedly identified the problem of scaling up to larger class sizes as a key open question in the field [10, 27, 28]. In order to allow the majority of STEM students and instructors to reap the demonstrated benefits of oral assessment, it is therefore critical that we devise and validate an effective and realistic means of implementing oral assessment in large classes. As STEM courses at many US universities (particularly the core courses) routinely contain hundreds of students, there is a significant gap in existing research on oral assessment.

The purpose of this study was to understand the practical approaches to implement oral exams in engineering classes as effective summative assessment components (as complements to existing assessments) to positively impact students' learning, while mitigating the potential challenges. The main research questions of this project are:

RQ1. What is students' overall psychological experience with oral exams?

RQ2. Students' learning experience: do students find oral exams to play a positive role in their own learning?

RQ3. How does the implementation of oral exams impact student's overall academic performance ?

RQ4. How to prepare Instructional Assistants to effectively administer the oral exam to scale it up to high-enrollment classes?

RQ5. How to prepare students for oral exams?

2. Methods

Our overall study is quasi-experimental study. We do not have a control group. Research questions that investigate students' perceptions were investigated through within-subject pre-and-post surveys. To study the impact on academic performance within the class, a few classes conducted semi-experiments. The semi-experiment conducted is elaborated on in a later section. All students participated in the intervention (oral exams) and they were invited to self-select into the research.

Site

This research was conducted at University of California San Diego (UCSD), a large public research institution in the United States. The study was based on collaborative efforts among faculty from Mechanical and Aerospace Engineering (MAE) and Electrical and Computing Engineering (ECE), Computer Science and Engineering (CSE) and educational researchers from the Teaching + Learning Commons at UCSD. Over the 3-year project period, a team of 7 faculty from MAE and ECE designed and implemented oral exams in 46 undergraduate engineering classes (9 unique courses).

- MAE 30A Statics and Introduction to Dynamics
- MAE 30B Dynamics and vibrations
- MAE 131A Solid Mechanics I

- MAE 131B Solid Mechanics II
- MAE 107 Computational Methods in Engineering
- MAE 8 MATLAB Programming for Engineering Analysis
- ECE 35 Introduction to Analog Design
- ECE 65 Components and Circuits Laboratory
- ECE 101 Linear Systems Fundamentals
- ECE 144 LabVIEW Programming: Design and Applications

Sample Population

A total of 4020 undergraduate engineering students from MAE and ECE participated in oral exams. The classes range from first-year to junior level, with class enrollment size from n=26 students to n=309 students. Students were asked for permission to use their course data (mainly performance) for research purpose. Thirteen students requested to opt out of the study, thus their performance data were removed from the research. All students who took the oral exams were invited to self-select to take the oral exams related surveys, and various response rates among classes were received. There were 71.68% of students responded to the pre-survey, 60.5% of students responded to the post-exam survey, and 36.12% of students responded to the end-of-quarter survey.

Data Collection

Survey data with both Likert scale and open-ended short-response questions were used to understand students' psychological experience with oral exams, the perceived impact of oral exams on their learning, and students' evaluation of assessor oral exams administration effectiveness. To study the impact of oral exams on students' learning outcomes, the performance data was used. To understand the effectiveness of the method we used to prepare students for oral exams, we investigate both students' psychological experience and learning outcome performance. The survey was held online. Student identities (IDs) were collected and de-identified by non-instructor research members and were then combined with demographic data and exam grades for analysis. To study the impact of oral exams on student performance, students' performance data were collected as a natural part of the course instruction.

Online surveys were sent at the beginning of the quarter, after each oral exam, and at the end of the quarter. All students who participated in the oral exams were invited to self-select into the research. Likert -scale questions were used as indicators of the impact of oral exams on students' learning experiences, complimented with open-ended questions to explore students' thoughts behind their rating. The indicators are:

1. Stress caused by oral exams. Students were asked to predict, report and summarize their views about the stress associated with oral exams. In the pre-survey, students were asked "I expect oral exam stress to be excessive", and "I expect written exam stress to be excessive". After each oral exam, students were asked to rate their level of agreement on "I found oral exam stress excessive", and "I found written exam stress excessive". At the end of the quarter, students were asked to rate their level of agreement on "I found oral exam stress excessive", and "I found written exam stress excessive".
2. How much do the students believe oral exams made them feel more comfortable reaching out to their instructors and TAs for help? In the pre-survey, baseline data was established by asking students to rate their level of agreement on "I feel comfortable reaching out to

the instructional team”. At the end of the quarterly survey, students were asked to rate their level of agreement on “oral exam makes me feel more comfortable reaching out to the instructional team”.

3. Students’ perception of how much oral exams increased their understanding of the subject matter. At the end of the quarterly survey, students were asked to rate their agreement level on “Oral exam increased my understanding of the subject matter”
4. Students’ perception of the impact the oral exam has on their learning strategy. Students were asked at the end of the quarterly survey to rate their level of agreement on “Oral exam changed my strategy in studying”.
5. Students’ perception of the impact oral exams had on their motivation to learn. During both post-exam and end-of-quarter surveys, students were asked to rate their level of agreement on “ Interaction during exam oral increased my motivation to learn”.
6. Oral exam administrator competency in both behavioral (tone, helpfulness, etc.) and technical aspects (questioning, accuracy of feedback, content knowledge, etc.).

The surveys aimed to elicit students’ insight about the impact of oral exams on their learning experience, how they prepared for the oral exams, and what they felt were the main benefits and drawbacks of oral exams.

Ethical Approval:

Ethical Approval was granted for the study by UCSD’s Institutional Review Board. Participants were briefed on the study and provided consent when they completed the online surveys. To protect participant anonymity, survey responses were de-identified by non-instructor project research members.

Analysis

We adopted several analysis approaches in this study: Student surveys included Likert scale responses with 5 levels of agreement: strongly disagree, disagree, neither agree nor disagree, agree and strongly agree. Descriptive statistics were conducted to understand the students’ overall agreement with the outcomes. Correlational analyses were conducted to understand how the oral exam impacted different sub-groups (such as gender, first-generation college students, etc), and nonparametric Kruskal-Wallis tests were conducted for the ordinal survey Likert scale question results. To analyze students’ open-ended short-responses, thematic coding was used for the open-ended responses using the qualitative data management software, Atlas.ti. To study the impact of oral exams on students’ learning, descriptive analysis and regression analysis were performed. More details are described in the results section.

3. Results and Discussion

3.1 Students’ overall psychological experience with oral exams

A. Students’ stress associated with oral exams

Concerns over students’ stress are commonly cited as one of the factors deterring instructors to adopt oral exams for their courses. It is commonly suspected that oral exams cause more stress on students due to their verbal communication aspect, lack of experience taking oral exams, and

other reasons. While stress is often a normal feeling that accompanies taking exams, high levels of stress can create a barrier to learning and performance, and is important to consider when designing assessments and other learning activities. Thus, we surveyed our students about their stress, in comparison to the written exam in both pre and end-of-quarter surveys. These results have been discussed in our previous paper [30, 31], and we are restating some of the key analysis and results to provide the overview.

Students' anticipation before taking oral exams

In our study, before taking any oral exams, many students expressed in the pre-survey, that they expect excessive stress during the oral assessments. There were 56.1% of the valid respondents who answered "agree/strongly agree" to the prompt "I expect the stress during the oral assessments to be excessive", while nearly 19.8% answered neutral, and 24.1% answered, "disagree/strongly disagree". In addition, we found the following few sub-groups of students anticipated a higher level of stress toward oral exams. More female students anticipated higher stress compared to male students ($p\text{-value} = 4.67e-08$). A total of 64% of female students agreed or strongly agreed that they expected excessive stress, while only 46% of male students did so. More First-Generation (FG) students anticipated high stress compared to non-FG students ($p\text{-value} = 1.33 e-07$). Sixty percent of FG students agreed and strongly agreed they expected the stress from the oral exams would be high, while 46% of non-FG students claimed the same. Students with different cumulative GPAs also presented different attitudes toward oral exams. Based on the post-hoc analysis to compare the different GPA student groups pairwise, we found more middle-performance (B and C range GPA) students expected high stress from oral exams, compared to high-performance (A-range GPA) and lower performance (below C GPA) students ($p\text{-value} = 0.0005$ for A and B students, and $p\text{-value} = 5e-06$ for A and C students). 52% of B-range GPA students and 64% students agreed or strongly agreed that the stress from oral exams would be excessive, compared with 43% A-range students.

Students' prior oral exams experience also impacts their expectations of stress. A pre-survey question asked the students how many times they have had oral exams before, with answers of "never", "yes but not for credits", "once/ twice", "several times", and "many times". Based on the post-hoc analysis to compare the different levels of prior experience of oral exams pairwise, we find that there is a strong significant difference between students who "never" took an oral exam with students who took oral exams "many times" ($p\text{-value} = 0.007$), as well as a less strong significant difference between students who "never" took oral exams and students who took oral exams "Several Times" ($p\text{-value} = 0.04$). Fifty-six percent of students had never taken oral exams, 46% who had taken oral exams, not for credits, 54% who had taken them once or twice, 45% of students who had taken them several times, and 36% of students who had taken oral exams many times. This seems to indicate that part of the students' stress towards oral exams comes from their lack of experience and/or familiarity with oral exams based on their previous academic experience.

The expected stress towards oral exams is also associated with students' English proficiency level. In the pre-survey, students were asked to self-report their spoken-English proficiency level, which varied from "no proficiency", "elementary proficiency", "limited working proficiency", "full professional proficiency", and "Native/bilingual proficiency". Very few students self-reported themselves with "no proficiency". Seventy-seven percent of students selected

“limited working proficiency”, 61% selected “professional working proficiency”, and 49% self-reported as having “full professional proficiency”. Forty-nine percent of “native/bilingual proficiency” students agreed or strongly agreed that they expected excessive stress from oral exams. It seems like lower English proficiency students are more likely to experience stress related to taking oral exams.

To better understand the root cause of the stress associated with oral exams - whether it is due to students’ unfamiliarity with oral exams or the inherent nature of oral exams, similar questions about written exams were also asked to conduct a comparison. Results showed that the following sub-groups of students self-reported statistically significantly higher anticipated stress towards written exams: female students, FG students, and middle-performance students (B and C- range GPA).

Thus, from the pre-survey, we can tell that female, first-generation, and mid-range GPA students usually experience higher exam-related stress, whether written or oral. Students’ English proficiency is the unique factor that contributes to oral exam-related stress. Students who have lower English proficiency experience higher levels of stress than with written exams.

The implication for instructors is that as for oral exams, non-native speakers and students who do not have much oral exam experience higher levels of stress compared to other students. To mitigate this challenge, one thing instructors can do is provide detailed information about the oral exams, how it is graded, how to prepare for them, and potential sample oral exams. Instructors could also emphasize that oral exams give them an opportunity to practice their communication skills, but their grade would be based on their understanding, not their language skills.

What was students’ stress level after taking oral exams?

Students were also asked to report their stress level **after each oral exam and at the end of the quarter** (the number of oral exams varies from class to class—usually one to three oral exams). Differences were noticed based on gender, FG status, and cumulative GPA sub-groups of students and were consistent with the pre-survey results: More female students expressed stress toward the oral exams they took compared to male students (p-value = 0.009); more First-generation college students expressed stress towards the oral exam they took compared non-first-generation (p-value = 0.019). High-performing students (A range GPA), identified less stress compared to middle-performance students (B and C range GPA) (A & B students comparison p-value = 0.0008, A & C students comparison p-value = 0.0001). The significant difference of the anticipated stress level among those who identified different levels of English proficiency vanished when students had the experience of taking an oral exam.

Post exam data were also collected on students’ experiences related to stress and written exams. The following group of students experienced statistically significantly more stress: Female students compared to male students, First generation compared to non-first generation, and students with middle-level GPAs. This trend is identical to the oral exam results. Thus, it seems that female students, FG students, and B and C-range GPA students are generally more stressed about exams, regardless of the format.

It is worth noting that, students who self-reported with “limited working proficiency” level English are slightly more stressed about the written exams compared to native speakers.

Comparing oral exams and written exams, overall, more students feel written exams are more stressful than oral exams. 24.1% of students reported that oral exams caused excessive stress, and 62.3 % of students reported that written exams caused excessive stress.

B. Does the oral exam experience make students more comfortable reaching out to the instructional team for help?

We were interested in understanding whether the one-on-one conversation opportunity between students and the instructional team (instructor and Instructional Assistants) impacts their relationship, either strengthening or weakening. In particular, we were interested in exploring the impact of oral exams on students’ comfort in reaching out to instructional team members for help. These results have been discussed in our previous paper [30,32], and we are restating some of the key analysis and results to provide the overview.

In the **end-of-quarter survey**, students were asked whether oral exams made them feel more comfortable reaching out to the instructional team for help. Overall, more students identified that taking oral assessments made them more comfortable reaching out to the instructional team for help. While a relatively large percentage (36.1%) of the students answered “neutral” on the prompt, there is a great gap in percentage between students who answered, “agree/strongly agree” (50.3%) and students who answered, “disagree/strongly disagree” (13.6%).

There were also some differences between the URM & non-URM student groups, and FG & non-FG students. More URM students (58%) agreed or strongly agreed that oral exams made them feel more comfortable reaching out to the instructional team for help, compared to 48% of students who claimed so, with p -value = 0.03. More FG students (59%) agreed or strongly agreed that the oral exams made them feel more comfortable reaching out for help, compared to 45% of students.

It is worth noting that from the pre-oral exam survey, there is very little difference between comfort levels in reaching out to the instructional team between the responses of URM students and Non-URM students. A similar trend is found between the responses of FG students and Non-FG students. Overall, more than 70% of the students agree or strongly agree that they felt comfortable reaching out to the instructional team for help at the beginning of the quarter. Participation in oral exams increased comfort levels.

In the **pre-survey**, students were asked to rate their agreement about their comfort in reaching out to the instructional team. Students who had more oral exam experiences agreed and strongly agreed that they felt comfortable reaching out to the teaching team for help. While more data is needed, this may indicate that oral exams have the potential to make students feel more comfortable reaching out to their professors or TAs for help.

Student responses to open-ended questions related to reasons students felt more comfortable reaching out for help gives due to oral exams were analyzed and coded. Many students’ responses related to the realization of how much the instructional team cared about their

learning, which made them more comfortable and more likely to reach out for help. Many students also commented on how the instructional team did not belittle them when they got something wrong, but instead helped them through it. This made students more comfortable with the instructional team because it showed them that the instructional team was not as intimidating as they may have previously believed.

C. Do oral exams increase students' motivation to learn?

This study also explored the impact of oral exams on students' motivation to learn. **After each oral exam and in the end-of-quarter survey** students were asked whether they felt the interaction during the oral exams they took increased their motivation to learn. Overall, more students identified feeling motivated to learn by the interactions during the oral exams. 69.1% of the valid responses answered "agree/strongly agree" to the prompt, while nearly 23.9% answered neutral, and only 6.9% answered, "disagree/strongly disagree". These results have been discussed in our previous paper [30,33], and we are restating some of the key analysis and results to provide the overview.

Student survey results showed a more significant impact on motivation to learn in First-Generation students and mid-range GPA (B and C) students. More FG students (80%) agreed or strongly agreed that the interaction during oral exams increased their motivation to learn, compared with 68% of non-FG students who reported so, with a p-value = 0.0017.

Based on the post-hoc analysis to compare pairwise the response from the different Cumulative GPAs, results showed a strongly significant difference between students in the "A range" and students in the "C range" (p-value = 0.002). Noting that although there is no significant difference between students from the "B range" and "C range", the difference is very close to being considered significant. The difference between FG and non-FG students suggests that oral exams can be a powerful tool to shorten the gap between FG and non-FG students.

Thematic coding and analysis of qualitative responses provided insight into potential reasons that oral exams contribute to student motivation. Students reported that oral exams revealed to them how much professors and other members of the instructional team care about their learning and well-being. Students found this increased their motivation to learn and increased their likelihood to reach out to the instructional team for help. In addition, in versions of the oral exams that were intended to give the students extra credit, students found that having a second chance to prove their knowledge increased their motivation to learn. This highlighted to them that the class was about increasing their knowledge rather than penalizing them for their mistakes.

3.2 Do students find oral exams play a positive role in their learning?

D. How did oral exams impact students' understanding of the subject matter?

In the end-of-quarter survey, students were asked whether they believe the oral exams increased their understanding of the subject matter. Overall, the majority of students found the oral assessment(s) increased their understanding of the subject matter. 72.1% of the valid responses answered "agree/strongly agree" to the prompt, while nearly 21.4% answered neutral, and only

6.4% answered, “disagree/strongly disagree”. These results have been discussed in our previous paper [30,32], and we are restating some of the key analysis and results to provide the overview.

There is no statistically significant difference among any demographic sub-groups. However, results showed that whether students believe oral exams increased their understanding of the subject matter is positively related to their belief on “whether they found the course materials interesting and engaging”, and “whether oral exams increased their motivation to learn”. Based on the posthoc analysis to compare pairwise the responses from different levels of agreement on “Finding the Course Material Interesting and Engaging”, there is a strongly significant difference between the response of students who strongly agree or agree that the course material is interesting and engaging (p -value = 0.00034). Results between students who strongly disagree that the course material is interesting and engaging and all other groups of students is not considered since the sample size ($n < 5$) is too small for this subgroup, which can cause unrepresentative results.

Coding and analysis of qualitative responses provide insight into potential reasons that oral exams increase students' understanding of the subject matter. Some students reported that due to the way they prepared for the oral exam, their strengths and weaknesses were exposed and it helped highlight what they should focus on in their studying.

Students found the instantaneous feedback aspect of the oral exam to be the most beneficial to their learning. Many students came to view the oral exam as a place where they could ask questions or where they could get clarification on their approaches. Looking at the distribution of the proportion of the responses from different levels of agreement on “Finding the Course Material Interesting and Engaging” significant differences are found. Although overall, the trend appears to be more students find oral exams increased their understanding of the subject matter. Students who disagree that the course is interesting and engaging slightly more agreed on the current prompt. Nearly all of the students, who strongly agreed that the course material is interesting and engaging, found their understanding of the subject matter had increased. This implies students' perception of other course aspects mediates their view about the implementation of oral exams. Rarely any course element alone could work by itself without influence or get influenced by other course elements.

E. Do oral exams change students' perceptions of changes to their learning strategies?

Assessment has the power to steer students' learning behaviors. The adaptive nature of oral exams, and the opportunities to follow-up on students' decision-making process for their problem-solving, has the potential to guide students' learning towards a deeper and conceptual level. They can also serve as a more authentic assessment tool than traditional written exams. Thus, in the **end-of-quarter survey**, students were asked to reflect on whether the oral exams changed their learning strategies. Overall, results show a quite even distribution of students' agreement level on how they find interactions during the oral assessment(s) changed their learning strategies. 29.4% of students agreed/strongly agreed on the prompt, while 38.1% of students didn't have a preference, and 32.4% of the students disagreed/strongly disagreed.

Results showed that more URM students, FG students, and students with lower GPAs (C and below C) reported oral exams caused a more significant change in their learning strategy

compared to the non-URM students, non-FG students, and higher and middle GPA (A and B) students. Thirty-eight percent of URM students agreed or strongly agreed that oral exams changed their learning strategy more towards deep learning, compared with only 26% claiming the same, with $P\text{-value}=0.021$. 37% of FG students agreed or strongly agreed that oral exams changed their learning strategy, compared to 24% of non-FG students, with $P\text{-value}=2.135e-05$. There were 20% of A-range GPA students, 33% of B-range GPA students, and 37% C-range GPA students agreed or strongly agreed that oral exams have changed their learning strategy toward deeper and conceptual mastery. There is a significant difference between A and B-range GPA students, as well as between A and C-range GPA students. This suggests that oral exams have the potential to help students to evaluate their learning strategies and make corresponding changes. However, results also showed that compared to the question “whether oral exams increased students’ understanding of the subject matter”, the impact on students’ learning strategy change is weaker. This could be due to a few reasons: First, not every student needs to change their learning strategies. Some high-performing students have been using effective learning strategies, and thus do not need changes. This is different from whether students increased their understanding of the subject matter: even the students who have used the right learning strategies may still benefit from an oral exam on a particular concept that is still unclear to them. Secondly, the change of learning strategies may need a longer process and multiple types of interventions. Most of the courses in this study implemented oral exams once or twice on average for each student, which may not be enough to make dramatic changes in students’ learning strategies. Literature ([34]-[35]) has also shown that it is difficult to change students’ learning strategies as they have developed their strategies from their past experiences, and people, and in general, are more likely to continue to use the strategies they feel useful or comfortable. Thirdly, students may lack the metacognition, the science of learning knowledge to make changes, even if they noticed they might need to change. Lastly, most of the oral exams implemented in this pilot study were relatively low-stakes in the overall weight of their grades (ranging from extra credits, pass-or-no-pass criteria, or 5% to 15% of their total grades). The low-stakes exams may push students to think less about their learning strategies.

Thematic coding and analysis provided insight into how students’ learning strategies have changed due to oral exams. Students find in preparing for their oral exams they spend more time focusing on their thought process or explanation skills than they would on a written exam in which they would focus on practice problems. Some students also report practicing their explanation aloud to ensure they could explain it. In addition, students highlighted focusing on concepts to be an important part of studying for oral exams rather than for the written exams which were more equation-based.

3.3 Impact of oral exams on students’ academic performance

A few classes used semi-experimental methods to study the impact of oral exams on students’ academic performance. Two cases are discussed in this paper.

1. Oral exams improves written exam performance

In one of the classes in the study, a controlled trial was performed to measure the impact of the oral exams. The class, MAE 30A, was a sophomore level class with 37 mechanical and aerospace engineering students that covered statics and introduction to dynamics. There were 3

midterms in the class, and after each midterm there were oral exams, but not all students completed each oral exam. Since oral exams were new to most students, each student was provided with 2 oral exams with the opportunity to drop the grade of the first oral exam. The grades on the oral exams contributed to 5% of the course grade. To implement this approach, all students were required to sign up for a 20-minute time slot following each midterm. The time slots started an hour after the midterm and continued through the following day. The students were notified via email right after the midterm if they were selected to take the oral exam. The student selection after the first midterms were random, but was adjusted for midterms 2 and 3 to ensure that each student completed 2 oral exams in the class. The written exams were conducted in-person, but the oral exams were conducted via video conference using Zoom. The exam questions were posted on the class Learning Management System (Canvas) immediately following the midterm so that students could prepare for the oral exam.

The controlled trial allowed for comparison of performance on written midterm 1 and midterm 2. The original research plan was to compare performance on midterm 2, with one group having taken an oral exam after midterm 1, and the control group not having taken an oral exam after midterm 1. However, using this grouping, there was not a large difference between the control and the intervention group. Since the research is exploratory at this stage, another grouping was explored to see if who administered the oral exam made a difference. The new grouping included the control group that did not take an oral exam (No OE1), the group that took the oral exam with the TA (TA OE1), and the group that took the oral exam with the faculty member (Faculty OE1). OE1 as an abbreviation for Oral Exam 1. The results are shown in Table 1, with the averages of each midterm shown and the standard deviation designated σ . About a third of the students are in each group, and there were 3 students who missed either an oral exam or a midterm, and thus were removed from the analysis.

Groups	Group Size	Midterm 1	Midterm 2	Percent Change
No OE1	13	75.4 $\sigma=20$	75.2 $\sigma=19$	-0.3%
TA OE1	10	71.5 $\sigma=19$	73.7 $\sigma=23$	3.1%
Faculty OE1	11	72.2 $\sigma=19$	82.3 $\sigma=13$	14.0%

Table 1: Raw Grades on Written Midterm 1 and 2

As seen in Table 1 the group that did not have an oral exam following midterm 1 had almost no change in their midterm 2 score. The group that took their oral exam with the TA had a 3.1% increase in grade, while the group that took the oral exam with the faculty member had a much higher increase at 14%. The grade on midterm 1 was used as an indication of incoming students' ability prior to any oral exam experience. There were slight variations in the midterm 1 grades among the groups, so the data was normalized by dividing the grades of midterms 1 and 2 by the average of midterm 1 grades for the group that the student belonged to. The normalized grades are shown in Table 2.

Groups	Group Size*	Midterm 1 Normalized	Midterm 2 Normalized	Percent Change
No OE1	13	1	0.997	-0.31%
TA OE1	10	1	1.031	3.08%
Faculty OE1	11	1	1.140	13.98%

Table 2: Normalized Performance on Written Midterm 1 and 2

The class size of MAE 30A was small, so it was not initially expected that this single trial could indicate a statistically significant difference between the groups. However, considering the large increase in grades among the students who took the oral exam with the faculty member, a one-way analysis of variance (ANOVA) was implemented by comparing the No OE1 group with the Faculty OE1 group. For each student the change in grade between midterm 1 and midterm 2 was correlated with their belonging in the No OE1 group of the Faculty OE1 group. The analysis was implemented in Matlab using `anova1` command. For the raw grades shown in Table 1 $p=.131$, and for the normalized grades shown in Table 2 $p=.123$. Both of these correlations are larger than the threshold of 0.05 that would indicate a statistically significant difference. Nevertheless, the current results indicate that oral exams were followed by an increase in grade in midterm 2, and that the increase in grade was substantially higher when the oral exam was administered by the faculty member. To establish a causal relationship continued studies with more students are required.

It should be noted that the TA was considered an excellent TA by both the faculty member and the students. The TA was in his final year of PhD studies in a topic area related to the course. This was his 3rd time TAing for a class in this sequence, and generally received higher student evaluations than the instructor.

Analysis of the impact of oral exams on midterm 3 was not practical. There were 8 different combinations of oral exam sequences; no oral exam, with TA, or with Faculty members in different orders (since each student was administered 2 oral exams in the class, there were no cases where oral exams did not occur after midterm1 and 2). Accordingly, the group sizes were mostly 3 students or less, which was not suitable for even analysis of averages. More details of this study can be found in [33].

2. Oral exam as early intervention strategy

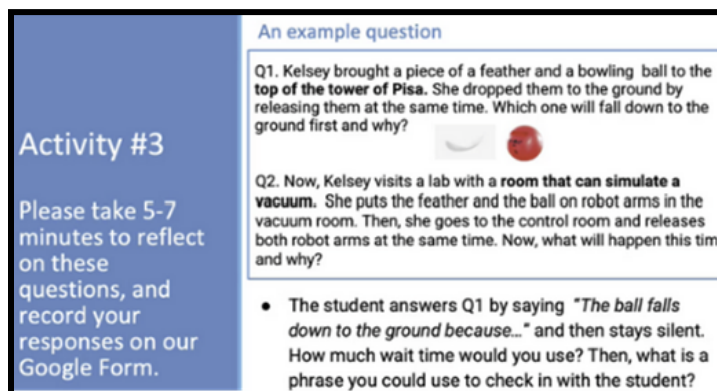
Another approach taken was to conceptualize the oral exam as an early intervention strategy. This was done in an ECE class of around 300 students in both Fall 2022 and Fall 2023. The underlying idea was to deploy an oral assessment where it would be most impactful: students who were struggling. This new approach was based on earlier observations in the same course in the first year of our project, when the oral assessment was done for all students. Students generally had positive reactions to the oral assessment and saw value in terms of self-assessment, receiving feedback from instructors and the ability to verbally explain their thought process.

However, we found that these benefits were most pronounced for students who were struggling with the class, and that they especially benefited from the in-person feedback component combined with affective effects on self-confidence and being more comfortable in seeking out additional help. Based on this observation, in later quarters, it was decided to only offer the oral exam to students who had failed a first written test and thus to recast the oral exam as an early intervention strategy for struggling students. The benefit was in scalability: only 26% of the students needed to be offered this intervention, while specifically targeting the subset of students who would benefit the most. Those students reported increased motivation to learn (82.8% agree or strongly agree) and more awareness of where they were struggling (93.1% agree or strongly agree). Similarly, these students reported that both taking and preparing for the exam increased their understanding of the material and rated it as the most impactful course element in terms of contributing positively to their learning. It also improved their comfort level in reaching out to the instructional team for help in the future (79.0 % agree or strongly agree, with no one disagreeing). More details of this study can be found in [36].

3.4 Prepare Instructional Assistants to effectively administer oral exams

To make oral exams applicable to large-enrollment classes, effectively engaging TA is critical. In our project, we have two parts for TA training: oral exam behavioral aspect training through asynchronous videos, and technical training led by course instructors.

For the behavioral aspect training, the project team developed and implemented oral exam administration training for TAs, which included five videos and reflection exercises: 1. Why use oral exams; 2. Adopting an equity mindset; 3. Reducing anxiety; 4. Growth mindset; and 5. Effective communication as the assessor. Each video is around 10-minute long. TAs were required to complete the training before giving their first oral exams. After completing each video, the TAs were required to complete a learning reflection. A sample question is seen in box1.



The image shows a Google Form interface. On the left, a blue sidebar contains the text: "Activity #3" and "Please take 5-7 minutes to reflect on these questions, and record your responses on our Google Form." The main content area is white and titled "An example question". It contains two questions, Q1 and Q2, and a bullet point. Q1 describes a physics experiment with a feather and a bowling ball at the top of the tower of Pisa. Q2 describes a similar experiment in a vacuum chamber. The bullet point provides a sample student answer for Q1 and asks for the wait time and a check-in phrase.

Activity #3

Please take 5-7 minutes to reflect on these questions, and record your responses on our Google Form.

An example question

Q1. Kelsey brought a piece of a feather and a bowling ball to the top of the tower of Pisa. She dropped them to the ground by releasing them at the same time. Which one will fall down to the ground first and why?

Q2. Now, Kelsey visits a lab with a room that can simulate a vacuum. She puts the feather and the ball on robot arms in the vacuum room. Then, she goes to the control room and releases both robot arms at the same time. Now, what will happen this time and why?

- The student answers Q1 by saying "The ball falls down to the ground because..." and then stays silent. How much wait time would you use? Then, what is a phrase you could use to check in with the student?

Box 1. A Sample Teaching Assistant Training Exit Question

The technical preparation were led by the course instructor. The main training methods are:

1. Mock oral exams. Instructor and TAs hold mock oral exams. During this process, TAs receive feedback from the instructor and peer TAs on both behavioral and technical aspects.

2. TA shadow in instructors's oral exams before giving their own oral exams.
3. Instructors review TAs oral exams recorded videos and provide feedback.
4. Engage TAs in the oral exams questions/ hints and rubric development process. Instructor need to clearly explain the design philosophy and provide sample questions, hints and grading rubric. This can help TA get familiar with the question early on, and reduce the time needed in mock oral exams. This is also a key method to reduce instructor's time investment later on.

F. How well did the assessor administer the oral exams? Is there a difference between the instructor and Teaching Assistants (TA)?

After each oral exam, we asked the students to evaluate how well the oral exams were administered, including clarity of speech, being respectful, being fair (no bias), assessor's mastery of course content, whether the assessor provided sufficient time for the student to solve problem, whether the assessor provided useful hints when needed (if this is applicable to the oral exam design intent for the courses), whether the assessor provided useful feedback about students' performance. Each of these questions has five levels of options are "very low", "low", "neutral", "high" and "very high".

Overall, the majority of students evaluated extremely positively the various aspects of the assessor's oral exam administration. Results show that for the first four aspects (clarity of speech, being respectful, being fair (no bias), and assessor's mastery of course content), less than 2% of the students negatively evaluated the assessors (instructors or TA).

Kruskal Wallis H tests were also applied to compare whether students' ratings for instructor and TA assessors vary, and if so, how much. Statistically significant differences were found on every aspect (except for "Provided sufficient time for me to solve problems on my own") of students' evaluation on different assessors (Professor/Instructor and a TA/Reader/Tutor). Clarity of speech with P-value = 0.0146, Being respectful with P-value = 0.002, Being fair (no bias) with Kruskal Wallis P-value = 0.0272, Mastery of course content with P-value = 0.0002, Provided sufficient time for me to solve problems on my own with P-value = 0.017, Provided useful hints when needed with P-value = 0.0018, Provided useful feedback about my performance with P-value = 0.1866. Although both the TA and instructor were rated really high, it appears that students overall believe the instructors did slightly better than the TAs. This difference may be a result of many factors, such as the instructor's knowledge, communication skills when interacting with students, etc.

3.5 How to prepare students for oral exams?

Students have varying previous experiences with oral exams. For our project, the majority of the students had very little to no oral exam experience. Rarely it is enough simply to tell students, in writing or verbally in class, what is required. Helping students get familiar with the format and content of oral exams is critical to reducing their anxiety about oral exams, as well as best preparing for them. In our project, we developed several tools to help students reduce the stress

that is caused by the unfamiliarity of oral exams: a short presentation to introduce the oral exams, sample oral exam videos filmed by the instructional team, and a written guide to the oral exam preparation.

The short presentation to introduce oral exams to students was given at the first lecture of the class. In the presentation, we discussed the pedagogical rationale of using oral exams and the benefits of oral exams for students learning. We emphasized to students that being able to articulate their technical ideas is a criterion of conceptual understanding and an important professional skill. In the presentation, instructors also discuss what the oral exams look like in the course, and how to prepare for it through the course learning activity.

The sample oral exam videos aim to help students gain more details about the oral exam assessor-student dynamics and grading rubrics. Two TAs cast the video, one played the assessor role and one played the student role. Three sample videos were produced, each demonstrating a different performance level: excellent, baseline, and progressing.

In the written guide for oral exam preparation, we talked about the motivation for implementing oral exams in this class, grading rubric and criteria for performance, the Do's and Don'ts, sample oral exam questions and solution keys, and the logistical details of oral exam sign-up.

It is also important to provide students the opportunities to practice for oral exams. One key aspect of preparing for oral exams is to engage in think-aloud while solving a problem, which students often fail to do by themselves. To encourage students to think aloud during problem-solving, MAE 30A added guidance questions in traditional engineering mechanics problem-solving questions. A sample is shown in box 2. The guidance questions prompt students to actively search their knowledge base and decide what to do for the next step when solving a problem. Answering these guidance questions encourages students to think about the conditions to apply engineering principles and procedural knowledge.

Video assignments can help students get used to technical oral communication. In our project, ECE 144 video assignment asked students to record a video and explain their LabVIEW programming thought process. Some students reported, while the video assignments helps them to practice oral communication and think aloud, they wish to receive feedback during the process. In MAE 30A and MAE 131A used group video assignments. Students work in a group of 3, each student lead the think-aloud problem-solving process, and the rest of the two members challenge or validate the leader. Students take turn to go through all homework questions. Students reported the group video assignments were very helpful to them in preparing for the oral exams, and also beneficial for their learning by exchanging ideas. More details of this study can be found in [37-39].

Think-Aloud Exercise Example –Statics

Part A - Guidance Prompts (20 points):

Answer each question within 2 sentences or less:

1. What assumptions can we make for this question? Can we consider it as an equilibrium problem? Why or why not?
2. What object(s) should we choose to study and draw the FBD for? How would you draw it? Are all the forces we are interested in concurrent to a point?
3. Is this a 2D or a 3D problem? How many linearly independent equations can we get and how many unknowns can we solve for based on one FBD? Using our assumption in prompt 1, what are these linearly independent equations?
4. How can we mathematically represent the forces shown in our FBD?
5. Did we make good use of all the information we are given? Are we missing any information in order to solve the problem? (In real-world scenarios, information is not given to us engineers need to identify what information to collect in order to solve a problem.)

Part B - Computations (80 Points):

Then solve the problem based on the strategies you formulated from the guidance questions.

- 2.55 A sailor is being rescued using a boatswain's chair that is suspended from a pulley that can roll freely on the support cable ACB and is pulled at a constant speed by cable CD . Knowing that $\alpha = 30^\circ$ and $\beta = 10^\circ$ and that the combined weight of the boatswain's chair and the sailor is 200 lb, determine the tension (a) in the support cable ACB , (b) in the traction cable CD .

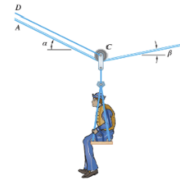


Fig. P2.55 and P2.56

Box 2. Sample think-aloud exercise in a Statics Class Homework Assignment

4. Discussion

In this study, we have explored how oral exams can impact engineering students' learning and learning experience, how to scale oral exams up to high enrollment classes, and how to prepare students for oral exams. In our experience, oral exams, regardless the various format and configurations, generally increased students' motivation to learn, their comfort levels in reaching out to the instructional team for help, their understanding of the subject matter, and provided information about study strategies that can help promote deeper learning and conceptual mastery. These positive impacts are significantly higher in First-Generation students, URM students, and students with lower GPAs. The interactive nature of oral exams and the opportunity for holding a conversation between students and members of the instructional team provides a unique experience for students that benefits their learning.

Some instructors may hesitate to use oral exams due to concerns about causing excessive stress and thus negatively impacting students' mental health. Results from this study showed that most students who experience stress about oral exams do so because of a lack of experience with oral exams, or because of concerns about English-speaking proficiency. Regarding concerns of lack of oral exam experience, providing students sufficient guidance, including sample oral exams, could significantly reduce this concern. For English-speaking proficiency concerns, the oral exams in our study aim to minimize the impact of language on oral exam performance, which was reflected in the rubric development. The post-exam surveys show that after students have some experience with oral exams, the concerns about language proficiency decreased significantly.

A main goal of implementing oral exams into the engineering courses that were a part of this study was to deepen students' conceptual understanding. While there is evidence from this study of the benefits of oral exams for students, the themes highlighted above reflect the benefits faculty experienced as educators. This resulted in faculty making various changes to their approaches to teaching with a goal toward inspiring student confidence and belief in their abilities, as well as helping students develop skills for conceptual learning.

Through appropriate training, TAs can effectively administer oral exams, which will address the scalability concerns for oral exams.

Finally, students need opportunity to understand the details of oral exams: how they are graded and how the oral exams look like through concrete exams. They also need opportunities to practice. Exercises that encourage students to practice think aloud, either in an individual or group setting, are effective to prepare students for oral exams.

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