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How I Teach It: Tips and Tricks for Oral Exams in Materials Thermodynamics and Electronic Materials Courses

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Abstract: Oral communication is a critical engineering competency. Typically, this skill is developed and evaluated using individual or group presentations. However, students will use this skill in a variety of professional settings not related to presentations such as team meetings, one on one meetings with clients, and technical interviews. An oral exam is a more authentic assessment for these situations and serves to prepare students for these professional settings in the future. This "how you teach it" paper will cover tips and tricks to giving oral exams in two common materials engineering courses. These tips and tricks include determining when oral exams take less time than written exams, coming up with questions, designing rubrics, and scheduling. Additionally, this paper will provide sample questions, handouts, and rubrics for oral exams for my materials thermodynamics and electronic materials courses.

Introduction and Background:

Oral communication is a key competency for engineers with communication skills specified by ABET as a student outcome[1] and oral communication specifically correlated with employability[2]. Oral communication competencies are typically evaluated through either individual or group presentations that are based on open-ended projects[3], [4]. However, practicing engineers engage in oral technical communication across a variety of contexts beyond presentations, including one-on-one or small-group meetings with team members and/or clients, networking events, and technical interviews.

In the age of Generative AI and Meta AI glasses, one assessment method gaining recent popularity that evaluates oral communication skills and technical knowledge are oral exams. This is because oral exams require spontaneous, real-time responses that reveal nuances in students' understanding and critical thinking [5]. Oral exams have been implemented in a variety of ways. Some instructors are replacing written mid-term exams with oral exams, especially as a formative assessment for those who are struggling with course content [6], [7]. I implement oral exams as the final exam in my courses. Oral exams are typically formatted as technical interviews to engage students' intrinsic motivation and help students engage more deeply with their learning [8], [9]. Oral exams have implemented as one-on-one interviews or as group interviews to help with scaling[10].

There is an emerging body of literature showing the pedagogical benefits of replacing written exams with oral exams. These benefits include increased student motivation[11], deeper engagement with their learning [12], higher performance on written final exams[6], [13], and lower DFW rates when oral exams were used as the mid-term exam or after the written mid-term exam for those struggling with the course material [6], [10], [13]. Additionally, there is evidence that oral exams probe students' understanding more accurately and more deeply. For example, in one study, researchers found that one quarter of their participants showed more nuanced understanding in their interview answers compared to their written exam answers on the same content[14].

While there are benefits to using oral exams, there are also concerns with implementation. One of the main concerns from faculty regarding implementing oral exams is scalability. There are a few studies that examine ways to scale exams to large class sizes where large means enrollment over 100 students [8], [15]. Researchers are investigating how using structured peer grading and group interviews can be used to scale oral exams to large class sizes (n>100-200)[8]. Another concern expressed by faculty is that oral exams are inequitable. How can we make sure that students are getting a consistent experience? Researchers are addressing this concern by investigating how to design questions and create robust rubrics [16]. Effective rubric design also has the added benefit of predicting students' performance on written final exams if oral exams are used as mid-term exams, especially if the rubrics have a higher granularity in their scale[6]. Finally, faculty are concerned that oral exams have a higher risk of academic integrity violations compared to written exams. There is evidence that cheating may not be as prevalent as some faculty think or if it is present, it doesn't seem to impact performance on the oral exams [17].

Basics of Oral Exams: What they are and examples of how they are structured

This section is to give an overview of what oral exams are and how they are structured for readers who have not experienced oral exams, have not implemented oral exams, nor are familiar with the diverse ways oral exams can be conducted.

An oral exam is an assessment technique where students demonstrate their conceptual knowledge or problem-solving abilities orally instead of in a written format. Oral exams are given in time periods ranging from five minutes to one hour per person depending on the purpose of the exam. They could be given outside of class in place of an exam or as in-class activities similar to short quizzes. Exams can be proctored by the instructor or by TAs if they are given sufficient training. They can be given as either a formative[18] or summative assessment[19], [20].

During the oral exam, instructors will ask questions that have or have not been provided in advance. Students will then answer these questions orally. The key part of what makes oral exams unique compared to other types of oral assessments is that there is interaction between the instructor and the student. Oral exams flow like a conversation with both the instructor and the student able to ask/answer clarifying or follow-up questions. After all questions have been discussed, the instructor has the option to give the student feedback or wait until all exams have been administered before posting grades and feedback. For the instructor, the interaction helps them better understand the breadth and depth of the student's knowledge and giving feedback allows them to better help the student. For the student, the interaction helps them clarify their knowledge in case they didn't understand what the instructor meant by a particular question. The combination of the interaction nature of oral exams plus instructor feedback helps students engage in mastery learning[21].

There is no one best format for oral exams. How instructors should run them depends on what their goals are. I recommend instructors consider the following at a minimum: 1) aligning the structure of the exam to the learning objectives that it assesses, 2) authentic engineering practices that the oral exam should simulate, 3) the length of the oral exam, 4) how questions are delivered to the students, 5) what students can bring to the exam, 6) how the oral exams will be graded, 7) how will students get their grade and feedback, 8) whether you want students to do the exam individually or as part of a group, and 9) creating an inclusive environment during the exam. The focus of this paper is to highlight two examples of oral exams that are designed to mimic technical interviews that assess different engineering skills and levels of Bloom's taxonomy (see Table 1).

Table 1: Differences in the structure of the oral exams for the Materials Thermodynamics course vs the Electronic Materials Course

Oral Exam Purpose and Structure	Materials Thermodynamics Course	Electronic Materials Course
Year of student	Sophomore	Junior
Learning objective(s) assessed	Identify how advances in materials thermodynamics have impacted society. (Remember level of Bloom's Taxonomy) Calculate thermodynamic variables of materials systems. (Apply level of Bloom's Taxonomy) Communicate your engineering knowledge orally and in writing. (Apply level of Bloom's Taxonomy based on communication of calculation questions)	Orally defend selection of a material for an electronic device that addresses a global economic, environmental, or societal need. (Evaluate level of Bloom's Taxonomy)
Engineering practice that the oral exam mimics	First-round technical interview	Second-round technical interview or a design review done as a practicing engineer
Length of exam, including time for feedback	20 minutes	25 minutes
How questions are delivered to students	Main questions posted on course website three weeks before the final exam week. Follow-up questions are not posted, and students are asked to keep these confidential during the oral exam.	
What students can bring to the exam	Their notes that have the answers to the questions. They are warned that overreliance on notes will impact their grade (see Appendix A). Things that will help with anxiety such as favorite drink/snack. Markers for the white board in my office if they have a favorite marker.	
How the oral exams will be graded	Rubric (see Appendix A)	Rubric (see Appendix B)
How will students get their grade and/or feedback?	Immediately after their oral exam as part of a post-exam debrief	
Individually or part of group?	Individually	Individually
Creating an inclusive environment	Allowing students to bring items that give comfort such as favorite drink/snack, adjusting lights/sounds of testing environment, providing accessible forms of the questions/rubric (e-reader versions, audio versions, etc…)	

General Approach to Designing, Implementing, and Grading Oral Exams

My goals when developing oral exams are to create an assessment that mirrors engineering practice, is built on best practices for improving oral competencies and inclusive assessment design and is time efficient while giving me good insight into students' knowledge and problem solving.

Based on these goals, I do the following steps when designing, implementing, and grading oral exams:

1. Before the term
   - If you did oral exams the year before, reflect on prior year's teaching journal
   - Decide on an oral exam format that mirrors engineering practice at a level appropriate for students' academic background
   - Refine oral exam format based on Universal Design for Learning principles
   - Reflect on literature regarding best practices for oral assessments
   - Build exam questions and rubric criteria based on course learning objectives
   - Scaffold course activities that help students prepare to do the oral exam on their own
   - Refine oral exam materials and course activities based on Universal Design for Learning principles before posting to course website

2. During the term
   - Refine course activities based on informal early feedback
   - Develop follow-up questions based on student performance on written exams related to oral exam content
   - Refine oral exam questions and rubric criteria before finals week
   - Post questions and rubrics three weeks before finals week
   - Discuss student anxieties around oral exams and brainstorm strategies that you and they could do to address concerns
   - Run activities to help students get comfortable with the oral exam format

3. Finals week
   - Conduct and grade oral exams
   - In between students, reflect on what went well and what didn't go well in teaching journal

4. After the term
   - Analyze the distribution of topics chosen
   - Analyze the distribution of grades across days of the week
   - Record thoughts and analysis in teaching journal

Best practices for designing oral assessments

I looked for meta-analyses or systematic literature reviews rather than individual studies to determine best practices. This led me to a systematic literature review by van Ginkel et al that developed seven design principles based on studies examining the relationship between course environment factors and oral presentation performance [22]. These design principles are reproduced in Table 2 for reference. I go into details about how I applied these principles in the course-specific sections.

Table 2: Seven Design Principles for Developing Oral Presentation Competence reproduced from Figure 2 in van Ginkel et al[22]

Reference Term/Phrase	Full Definition
Instruction	**Instruction**
1. Learning objectives connected to oral exam criteria	1. Ensure that learning objectives are communicated explicitly to students and are specifically formulated in relation to criteria of oral presentations in order to increase self-efficacy beliefs and oral presentation competence.
2. Student perception of authenticity and relevance	2. Ensure that the learning task –the presentation assignment–is related to content of the particular discipline considered as relevant by students, the complexity of the task develops through the course and students perceive the context of the task as 'authentic' to enhance self-efficacy beliefs, oral presentation competence and to decrease communication apprehension.
Learning Activities	**Learning Activities**
3. Examples	3. Provide opportunities for students to observe models of peers or experts to increase self-efficacy beliefs and oral presentation competence.
4. Practice	4. Provide opportunities for students to practice their oral presentations in order to develop their oral presentation competence and to decrease their communication apprehension.
Assessment Strategy	**Assessment Strategy**
5. Feedback	5. Ensure that feedback is explicit, contextual, adequately timed and of suitable intensity in order to improve students' oral presentation competence.
6. Peer involvement	6. Encourage the involvement of peers in formative assessment processes in order to develop students' oral presentation competence and attitudes towards presenting.
7. Self-assessment	7. Facilitate self-assessment using videotaping and portfolios to encourage students' self-efficacy beliefs, oral presentation competence and attitudes towards presenting.

Best practices for creating inclusive assessments

For inclusive assessment best practices, I applied principles from the Universal Design for Learning framework (see Figure 1)[23]. Specifically, I provided multiple means of engagement. Students got to choose what topics their oral exam covered (i.e., recruiting interest), received detailed rubrics ahead of time (i.e., self-regulation), and answered a question about reflecting on their learning as part of the oral exam (i.e., self-regulation). I go into details about what that looks like for each course in the course-specific sections of this paper.

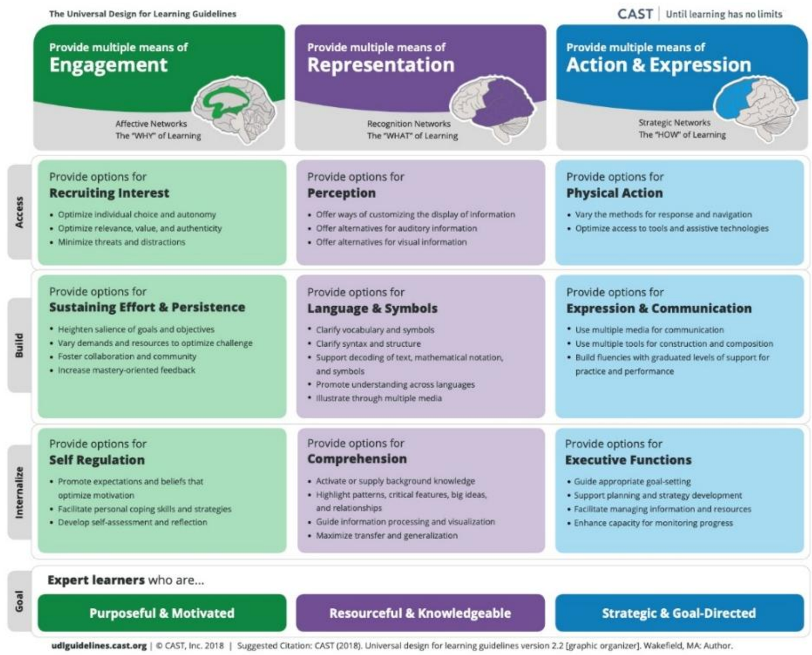

Figure 1: Universal Design for Learning Framework[23]

Designing and Implementing Oral Exams for the Second-Year Thermodynamics Course

Step 1: Before the term

Deciding on an oral exam format based on engineering practice and students' academic background

I designed the oral exams in this course to mirror engineering practice by modeling them off technical interviews. Practicing engineers use oral communication skills outside of presentations in situations such as team meetings, client meetings, and design reviews. Undergraduate students typically experience these types of scenarios within technical interviews. Framing assignments within career-relevant contexts engages students' intrinsic motivation, which makes them more likely to engage with learning.

I designed the technical interview questions to be based on conducting and justifying calculations based on students' academic background. Students in Materials Thermodynamics are second year students who have taken the introduction to materials engineering course and a course in materials microscopy. At this point, student are comfortable doing calculations and should understand why they are applying equations to specific problems. Oral exams are new types of assessments that can cause anxiety, so designing the questions in terms of something they are comfortable with helps them feel more comfortable. I don't have data to support this, but anecdotally I have had dozens of students tell me something similar over the seven years I have been doing oral exams.

Connecting oral exam questions and rubric criteria to learning objectives

The Materials Thermodynamics course has the following learning objectives:

1. Explain the laws of thermodynamics in words and equations.
2. Design materials synthesis and processing methods using principles of thermodynamics.
3. Explain the thermodynamic principles governing phase equilibria and point defect formation in crystalline materials.
4. Calculate phase diagrams for unary and binary materials systems.
5. Identify how advances in materials thermodynamics have impacted society.
6. Communicate your knowledge orally and in writing.

Table 3 shows the relationships between the course learning objectives, specific questions, and rubric criteria.

Making oral exams accessible and inclusive through Universal Design for Learning Principles

I make the Materials Thermodynamics oral exams accessible and inclusive in three ways.

First, I apply strategies from the multiple means of engagement principles of Universal Design for Learning. I recruited interest by creating calculation and design problems themed around four different companies that our students have gone to work for and are related to a variety of materials systems (e.g., Alcoa for metals and Dow Chemical for polymers). Students were able to choose which company to do for the oral exam depending on the area of materials they are interested in going into. I also encouraged self-regulation by providing the rubrics ahead of time that laid out expectations for both the listed problems and the problem solving and reflection portion. Additionally, I ask students to reflect on their learning and how they plan to apply what they've learned in their careers.

Second, the oral exam format the provided handouts are designed to be read by e-readers and all figures contain alt-text. I am currently working on creating audio versions of the questions with sight-related disabilities.

Third, I build accessibility into the scheduling process. When students sign up for a timeslot, they send me their top three times and can change their times up to an hour before their timeslot. This allows for flexibility. Additionally, the oral exam format can accommodate those with disability accommodations. When a student has an extended testing accommodation, I reach out to them and ask if they would like to use the extended testing time for the oral exam. Those who do use their accommodation then sign up for back-to-back slots.

Table 3: Connections between course learning objectives, specific problems on the oral exams, and rubric criteria.

Materials Thermodynamics Course Learning Objectives	Alcoa Interview		Air Liquide Interview Question and Rubric Criteria		Dow Chemical Interview Question and Rubric Criteria		Lebronze Alloys Interview Question and Rubric Criteria	
	Question	Rubric Criteria	Question	Rubric Criteria	Question	Rubric Criteria	Question	Rubric Criteria
2. Design materials synthesis and processing methods using principles of thermodynamics.	Problem 3	Appropriately uses equations to calculate the thermodynamically stable crystal size. Appropriately uses thermodynamic concepts to select casting type. Appropriately uses thermodynamic concepts to identify the problem and the solution.	Problems 2 and 3	Applies appropriate equations and thermodynamic concepts to calculate the temperature and pressure needed to maximize gas yield. Applies thermodynamic equations to calculate the design parameters.	Problem 2	Appropriately uses thermodynamic concepts to design the distillation process. Applies thermodynamic equations to calculate the relevant design parameters.	Problem 3	Identifies an appropriate way to achieve the vacancy concentration at 500^{o}C for a sample at room temperature. Appropriately uses concepts to justify their approach.
3. Explain the thermodynamic principles governing phase equilibria and point defect formation in crystalline materials.	Problem 2	Applies appropriate course concepts to determine whether a eutectic phase will form.	Not assessed	Not assessed	Not assessed	Not assessed	Problem 3	Identifies an appropriate way to measure vacancy concentrations. Justifies why that technique over others. Appropriately uses concepts when estimating the enthalpy of vacancy formation and calculating the vacancy concentration.
4. Calculate phase diagrams for unary and binary materials systems.	Problem 2	Applies appropriate equations to calculate the eutectic composition. Applies appropriate equations to calculate the eutectic temperature.	Not assessed	Not assessed	Not assessed	Not assessed	Problem 2	Applies appropriate course concepts when explaining how they calculated the phase diagram. Accurately estimates the interaction parameter. Uses appropriate concepts and equations.
5. Identify how advances in materials thermodynamics have impacted society.	Problem 1c	Identified at least one economic, social, and political factor that influenced their design AND explained how their design accommodates those factors.	Problem 1b	Identified at least one economic, social, and political impact of sourcing, manufacturing, or using the gas on society.	Problem 1b	Identified at least one economic, social, and political impact of sourcing, manufacturing, or using 1-proponal on society.	Problem 1b	Identified at least one economic, social, and political impact of sourcing, making, or using Cu-Ni spinodal alloys.

6. Communicate your knowledge orally and in writing	Rubric Criteria: Clarity in communicating knowledge and problem solving. Student answers the question that was asked, Students' answers are concise, and Uses appropriate data or figures when explaining their solutions.

Reflect on best practices in oral assessment literature: Applying van Ginkel's Seven Design Principles

Table 4 shows an overview of how I incorporated van Ginkel's seven design principles when implementing oral exams into this course.

Table 4: How van Ginkel's seven dimensions are implemented in the Materials Thermodynamics Course

Reference Term/Phrase	Design and Preparation	Implementation
Instruction		
1. Learning objectives connected to oral exam criteria	Connect course learning objective to each **oral exam question** and **rubric category**.	**Explain** to students in class how the oral exam questions are **connected to the course learning objectives**.
2. Student perception of authenticity and relevance	Questions themed around an **engineering company** that designs products/processes aligned with course content. Student handout connects oral exam purpose and structure to **technical interviews**	**Explain** to the students in class how the oral exam is **connected to engineering practices** and why engaging with it will help them prepare for their career. Get perceptions of the oral exam from students during **informal early feedback** halfway through the course.
Learning Activities		
3. Examples	Reach out to students from prior year to come visit class for a **demonstration.**	Students from prior year visits class to **model** oral exam in front of the class.
4. Practice	**Post an old exam question** a week before the practice day. Tell students what to expect and that there will be a demonstration.	After seeing upperclassmen example, students **practice** with each other.
Assessment Strategy		
5. Feedback	**Decide how** you will give feedback during the practice activity. Will it be written feedback given after class or oral feedback during class?	**Observe** student groups and **make notes** regarding general behavior
6. Peer involvement	**Decide how** you want students to give each other feedback. Consider creating a **feedback form** to fill out or using the **oral exam rubric** to guide students' discussions with each other.	Students give **open-ended** feedback with each other after practicing
7. Self-assessment	Incorporate self-assessment as one of the **categories on the rubric**	Ask students **what they learned** and **how they will use** what they learned for their career

Step 2: During the term

Scaffold course activities that help students prepare to do the oral exam on their own

The goal is for students to feel comfortable and be able to excel at the oral exams on their own. Because many students at this stage have not experienced an oral exam, I take care to scaffold course activities to help familiarize themselves with this way of accessing and expressing their knowledge. To do this, I scaffold activities to help bring students through their zone of proximal development. This concept, developed by psychologist Vygotsky, claims that deep learning occurs in the space between when students cannot accomplish a task even with help and when students can accomplish a task with no help[24]. In this middle space, the zone of proximal development, students need the help and guidance of others, including peers and instructors. Table 5 shows the organization of the course topics and course activities that support helping students navigate from being unable to express their knowledge orally to completing an oral exam on their own.

Table 5: Materials Thermodynamics course schedule showing the progression of topics, where the oral exam questions for each company are pulled from, and course activities that help students develop skills necessary for oral exams.

Week	Topics	Oral Exam Questions	Oral Exam Scaffolded Activities	Oral Exam Design and Implementation
1	0^{th} and 1^{st} Laws of Thermodynamics Enthalpy of Chemical Reactions	Air Liquide Interview	Discuss oral exam logistics and motivation when introducing assignments on the syllabus	Finish rough draft of oral exam questions for each company
2	Applications of Enthalpy: Calorimetry and Materials Characterization	Dow Chemical Interview		
	Entropy of Chemical Reactions	Air Liquide Interview		
3	Gibbs Free Energy of Chemical Reactions	Air Liquide Interview		
	Applications of Gibbs Free Energy: Batteries	Not part of the oral exam questions		
4	Applications of Gibbs Free Energy: Casting	Alcoa Interview		Create rough draft of follow up questions
	Exam 1		Homework 1 and Exam 1 covers calculation and design problems similar to Air Liquide and Dow Chemical oral exam problems	
5	Ellingham Diagrams	Alcoa Interview		
6	Unary Phase Diagrams and Vapor Pressure	Alcoa Interview		Finalize follow up questions
7	Exam 2		Homework 2 and Exam 2 covers calculation and design problems similar to Alcoa oral exam problems	
8	Liquid/Gas Binary Phase Diagrams	Dow Chemical Interview		Oral Exam questions are posted to course website
	Liquid/Solid Binary Phase Diagrams	Lebronze Alloys		
9	Eutectic Points on Phase Diagrams	Alcoa Interview		Students email me to schedule appointment during finals week
	Spinodal Decomposition Points on Phase Diagrams	Lebronze Alloys		
	Thermodynamics of Point Defect Formation	Lebronze Alloys		
10	Oral Exam Practice		Students see example of oral exam in class from prior students and then practice with each other	
	Exam 3		Homework 3 and Exam 3 cover calculation and design problems similar to Alcoa, Dow chemical and Lebronze alloys oral exam problems	
Finals Week				Students come to my office for their oral exam. Exam is 20 minutes long with 5 minutes at the end for feedback, including explaining their grade.

Designing and Implementing Oral Exams for Third-Year Electronic Materials Course

Step 1: Before the term

Deciding on an oral exam format based on engineering practice and students' academic background

Like the Materials Thermodynamics course, I designed the oral exams in this course to mirror engineering practice by modeling them off technical interviews. However, the students in the Electronic Materials course are third-year students. They have taken several materials engineering courses and are ready for more advanced learning objectives (e.g., Create and Analyze level of Bloom's taxonomy). Thus, I modeled the technical interview as a proposal for whether a company should explore an alternative material for an electronic device.

Connecting oral exam questions and rubric criteria to learning objectives

The Electronic Materials course has the following learning objectives:

1. Identify the standard and novel metals and semiconductors used in electronic applications.
2. Explain how semiconductors are different from metals.
3. Evaluate commonly used and cutting-edge manufacturing techniques used to make electronic devices.
4. Model a material's electrical properties using classical and quantum models.
5. Explain the relationship between structure, properties, processing, and performance of materials used in electronic devices.
6. Orally defend selection of a material for an electronic device that addresses a global economic, environmental, or societal need.
7. Measure electrical properties of materials and performance of electronic devices and circuits.
8. Evaluate scientific studies that investigate the relationship between structure, properties, processing and performance of materials used in electronic devices.
9. Conduct experiments safely.
10. Delegate project responsibilities equitably, in ways that leverage team members' strengths, and in ways that encourage team members to develop new skills.

The oral exams are based on lecture content, which is associated with learning objectives 1-6. Table 6 shows the relationships between course learning objectives 1-6, specific questions, and rubric criteria.

Making oral exams accessible and inclusive through Universal Design for Learning Principles

Like the Materials Thermodynamics course, I make oral exams in the Electronic Materials course accessible and inclusive in three ways.

First, I apply strategies from the multiple means of engagement principles of Universal Design for Learning. I recruited interest by allowing students to choose an electronic device of their choosing, and what material they propose to replace it with. Justifying whether to replace an existing material encourages students to engage in materials selection, which is a cornerstone of engineering practice for this discipline. I also encouraged self-regulation by providing the rubrics ahead of time that laid out expectations for both the listed problems and the problem solving and reflection portion. Additionally, I ask students to reflect on their learning and how they plan to apply what they've learned in their careers.

Second, the oral exam format the provided handouts are designed to be read by e-readers and all figures contain alt-text. I am currently working on creating audio versions of the questions for those with sight-related disabilities.

Third, I build accessibility into the scheduling process. When students sign up for a timeslot, they send me their top three times and can change their times up to an hour before their timeslot. This allows for flexibility. Additionally, the oral exam format can accommodate those with disability accommodations. When a student has an extended testing accommodation, I reach out to them and ask if they would like to use the extended testing time for the oral exam. Those who do use their accommodation then sign up for back-to-back slots.

Table 6: Connections between course learning objectives, specific problems on the oral exams, and rubric criteria.

Electronic Materials Course Learning Objectives	Question/Instructions	Rubric Criteria
1. Identify the standard and novel metals and semiconductors used in electronic applications.	Select an electronic device that you are interested in and benefits society. Select a material that you believe will improve the function of the device over the material currently used.	Are the materials identified as industry standard actually standard and the novel materials actually novel? This criteria is not in the rubric explicitly but is part of the instructions
3. Evaluate commonly used and cutting-edge manufacturing techniques used to make electronic devices.	Structure-Properties-Processing relationship: Do you describe the relationship between structure, properties, and processing that leads to the material's performance? Performance: Do you explain how the performance of the material is evaluated? How does this material perform compared to the standard material used? Do you explain why the materials perform differently?	**Follow up question:** How would you predict the effect of [insert processing technique here] on your material's structure or properties?
5. Explain the relationship between structure, properties, processing, and performance of materials used in electronic devices.	Structure-Properties-Processing relationship: Do you describe the relationship between structure, properties, and processing that leads to the material's performance?	**Follow up question:** How would you predict the effect of [insert processing technique here] on your material's structure or properties? Gives second example of how the relationship between structure-properties-processing leads to the material's performance in the device.
6. Orally defend selection of a material for an electronic device that addresses a global economic, environmental, or societal need.	Material selection: Would you recommend companies switch to your material over the one currently used now? In the next 5 years? In the next 20? Ever? Societal Importance: Do you explain how the device benefits society? Do you explain how switching to this material from the standard material used would impact people, positively or negatively?	Use specific details from their pre-exam research to explain the positive and negative impacts of using their proposed material. Identifies the specific group(s) impacted and how they are impacted. Identifies whether material is a good choice to replace the industry standard material. Identifies what would need to happen for material to feasibly be adopted by industry.

Reflect on best practices in oral assessment literature: Applying van Ginkel's Seven Design Principles

Table 7 shows an overview of how I incorporated van Ginkel's seven design principles when implementing oral exams into this course.

Table 7: How van Ginkel's seven dimensions are implemented in Electronic Materials course

Reference Term/Phrase	Design and Preparation	Implementation
Instruction		
1. Learning objectives connected to oral exam criteria	Connect course learning objective to each **oral exam question** and **rubric category**.	**Explain** to students in class how the oral exam questions are **connected to the course learning objectives**.
2. Student perception of authenticity and relevance	Students can choose electronic device and materials to investigate as part of their oral exam Student handout connects oral exam purpose and structure to **technical interviews centered on materials selection**	**Explain** to the students in class how the oral exam is **connected to engineering practices** and why engaging with it will help them prepare for their career. Get perceptions of the oral exam from students during **informal early feedback** halfway through the course.
Learning Activities		
3. Examples	Reach out to students from prior year to come visit class for a **demonstration.**	Students from prior year visits class to **model** oral exam in front of the class.
4. Practice	**Post an old exam question** a week before the practice day. Tell students what to expect and that there will be a demonstration. Students lead small-group discussions that analyze scientific studies. Discussions prepare students for one-on-one nature of the oral exam.	After seeing upperclassmen example, students **practice** with each other.
Assessment Strategy		
5. Feedback	**Decide how** you will give feedback during the practice activity. Will it be written feedback given after class or oral feedback during class?	**Observe** student groups and **make notes** regarding general behavior
6. Peer involvement	**Decide how** you want students to give each other feedback. Consider creating a **feedback form** to fill out or using the **oral exam rubric** to guide students' discussions with each other.	Students give **open-ended** feedback with each other after practicing
7. Self-assessment	Incorporate self-assessment as one of the **categories on the rubric**	Ask students what they learned and how they will use what they learned for their career

Step 2: During the term

Scaffold course activities that help students prepare to do the oral exam on their own

Like in the Materials Thermodynamics course, I scaffolded activities to get students comfortable with this new way of doing oral exams. In addition to the scaffolding activities described in the Materials Thermodynamics course, I added a scaffolding activity that helps students identify and evaluate common and novel materials, manufacturing approaches, and characterization methods. I call this activity Journal Club as it is modeled after the journal clubs graduate students do in their PhD programs. For those unaware of the term, Journal Club is when someone chooses a scientific study for the group to analyze. They send it out to the group usually a week ahead of time and the group meeting is spent analyzing the paper as if they were peer reviewers.

For the Journal Club activity, a sub-set of students are selected to be group leaders. These students select a paper relevant to a course topic from a list that I provide. The students post this paper to the discussion board on the course website. The rest of the students post questions, which the group leaders use to prepare for the in-class discussion. Like in the oral exam, group leaders are responsible for doing outside research and to evaluate the merits of a particular material, processing technique, or characterization method. During the in-class discussion, I sit in on the groups and listen to how students orally communicate their knowledge and give feedback to both the group leaders and the other students. I then ask students to give feedback to each other. Over the course of three Journal Club discussions, all students have the chance to be a group leader and a group member. To give feedback and to receive feedback.

Table 8 shows the organization of the course topics and course activities that support helping students navigate from being unable to express their knowledge orally to completing an oral exam on their own.

Table 8: Materials Thermodynamics course schedule showing the progression of topics, where the oral exam questions for each company are pulled from, and course activities that help students develop skills necessary for oral exams.

Week	Topics	Oral Exam Scaffolded Activities		Oral Exam Design and Implementation
		Lecture	Lab	
1	Classical Model of Conductivity	Discuss oral exam logistics and motivation when introducing assignments on the syllabus	Discuss journal club activities and how they will support students' preparation for the oral exam when introducing the lab syllabus	Finish rough draft of oral exam questions for each company
2	Electromigration		Students practice leading discussions that analyze scientific studies in small groups	
3	Quantum Mechanical Model of Conductivity			
4	Intrinsic Semiconductors			Create rough draft of follow up questions
	Exam 1	Homework 1 and Exam 1 cover common and novel metals in electronic devices and their Structure – Property – Processing – Performance	Students practice leading discussions that analyze scientific studies in small groups	
5	Extrinsic Semiconductors			
	Schottky vs Ohmic Contacts			
6	IV Curves PN-Junctions and Metal/Semiconductor Contacts			Finalize follow up questions
	MOSFETs			
7	MOSFETs			
8	CZ Growth			Oral Exam questions are posted to course website
	Exam 2	Homework 2 and Exam 2 cover common and novel semiconductors in electronic devices, their Structure – Property – Processing – Performance, and common electronic devices	Students practice leading discussions that analyze scientific studies in small groups	
9	Thermal Oxidation			Students email me to schedule appointment during finals week
	Doping Processes			
10	Oral Exam Practice	Students see example of oral exam in class from prior students and then practice with each other		
	Exam 3	Homework 3 and Exam 3 common and emerging aspects of electronic materials manufacturing		
Finals Week				Students come to my office for their oral exam. Exam is 25 minutes long with 5 minutes at the end for feedback, including explaining their grade.

Addressing Common Concerns

Concern #1 Academic Integrity: Won't students talk to each other and find out the follow-up questions?

I completely understand where this concern comes from. That being said, I have not observed this occur in my courses. Appointments run Monday through Friday of finals week. About 80-90% of the appointments occur Monday through Wednesday with the rest usually occurring on Friday. Students certainly have ample time to talk to each other. If students were talking to each other, I would have seen more confident answers on the follow-up questions, which I did not see. I also would expect to see higher grades the further into the week, which I do not see. There is no correlation between what day of the week students take the oral exam and their grade on the oral exam. There is instead a small correlation between students' average exam score and their final exam score, which I would expect to see. Unfortunately, I cannot share this data because I did not obtain IRB approval nor students' consent to share data.

While I cannot share my data, other researchers have also observed that scores on oral exams do not depend on the order that they were taken [17]. This finding occurred within a dataset taken over a fifteen-year period, suggesting students are less likely to cheat on this type of assessment. My suspicion is because I give students autonomy to pick their topic, students see the assignment as valuable, and the final exam is not a large portion of the overall course grade, which has been shown to lower instances of cheating.

Concern #2 Grading: This can't scale very well. Won't this take too long to grade compared to written exams?

This is a valid concern. Before I get into how I go about managing the time needed to do oral exams, please keep in mind that I am the only instructor for both courses and I do not have the help of Teaching Assistants. There are papers that show how to use scale administering oral exams using multiple instructors and Teaching Assistants. The Teaching Assistants need training but after that can be an effective resource when scaling oral exams to courses with more than 100 students enrolled.

With my current set up, I only do oral exams for my final exam. Finals week is easily my most free week in terms of scheduling, which allows me to schedule the 50-60 students I do oral exams for. When putting together this paper, I discussed with other colleagues on how long they take to grade their written final exams and found that it ranged from 10 – 25 minutes per exam when they gave partial credit and had short/long answer questions.

Before I get into calculating the time required for oral vs written exams, I think it's worth thinking about what your goals and priorities are with assessments. If you're going to compare multiple choice exams with oral exams, then yes, of course oral exams will take longer to implement and grade. For the sake of argument, say that we're comparing oral exams to a written exam with calculations and short/long answers, which is the closest in form to the oral exams described in this paper. At what point do oral exams take an equivalent or less amount of time while giving similar or better levels of information about student understanding?

To answer this, I developed an equation that calculates grading time for written exams and for oral exams. Both equations are functions of how long it takes to administer them, how long it takes to grade them, total enrollment, and number of unique sections.

The total time it would take to administer and grade a written final exam is as follows:

$$t_{written} = t_{exam\ time\ slot} * N_{sections} + t_{grade\ per\ exam} * N_{students}$$

where $t_{written}$ is the time it takes to administer and grade all written final exam in hours, $t_{exam\ time\ slot}$ is the time it takes to administer the final exam in minutes, $N_{sections}$ is the number of sections of the course that you teach, $t_{grade\ per\ exam}$ is the time it takes to grade per exam in minutes, and $N_{students}$ is the number of students across all sections.

The total time it would take to administer and grade an oral final exam is as follows:

$$t_{oral} = t_{exam\ time\ slot} * N_{students}$$

where t_{oral} is the time it takes to grade to administer all oral exams in hours, $t_{exam\ time\ slot}$ is the time it takes to administer the final exam in minutes and $N_{students}$ is the number of students across all sections. Grading and administering the oral exams occur at the same time, which is why there is only one term in this equation.

For my Materials Thermodynamics course, there are typically 60 students enrolled spread across two sections. When I grade their written exams, I typically spend about 15 minutes per exam depending on the level of feedback and partial credit. Their oral exams are 20 minutes long, including the time used to give the student feedback. Using the equations above, the total time I would spend grading their final exam if it was a written exam is approximately 20.67 hours. Conducting and grading oral exams for each student would take approximately 20 hours. This is a difference of 40 minutes. Figure 2 shows the time difference between the two as a function of total enrollment, assuming 48 students per section.

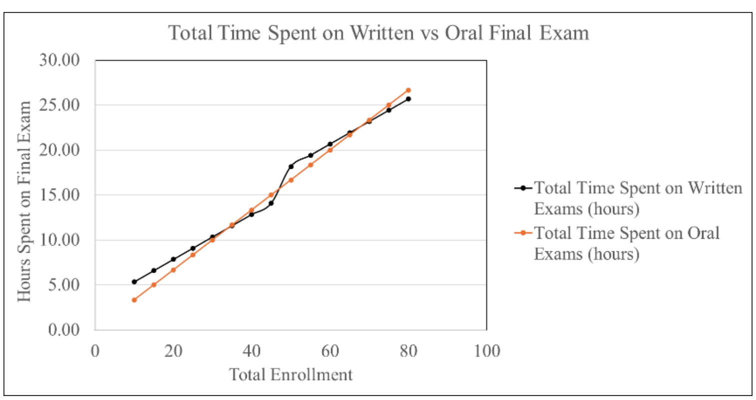

Figure 2: Total amount of time it takes to administer and grade written vs oral exams in my Materials Thermodynamics Course.

For my Electronic Materials course, there are typically 60 students enrolled spread across two sections. Their final exam questions are more open-ended, and they can choose the material they want to analyze. As a result, I estimate it would take me longer to grade each exam compared to the materials thermodynamics final exam, which are the same questions and more calculation based. I estimate that I would spend closer to 20 minutes per exam in this case. The Electronic Materials course's oral exams are 25 minutes long, including the time used to give the student feedback. Using the equations above, the total time I would spend grading their final exam if it was a written exam is approximately 25.67 hours. Conducting and grading oral exams for each student would take approximately 25 hours. This is a difference of 40 minutes, just like in the Materials Thermodynamics case.

Concern #3 Grading Equity: How do you know the problems are of equal difficulty? Do all students pick the "easiest" one?

There are four options for students to pick from in the Materials Thermodynamics oral exam. To ensure equal difficulty, I make sure that the same Bloom's Taxonomy objectives are present in each company option. Each company has a calculation-focused question (Apply), a design or processing-focused question (Create), a societal impact question (Evaluate), and an application-focused question (Understand).

Typically there is an even distribution of which option students pick with a slight preference for the Alcoa followed by the Lebronze alloys options. I mostly attribute that to the metallurgy focus in our department rather than the question difficulty. I also do not see any significant difference in grades across the different options.

For the Electronic Materials oral exam, students answer the same questions. The source of difficulty comes from what electronic device and material they choose to explore for their exam. Even relatively simple materials like Silicon provide ample opportunity to explore students' foundational knowledge. Instead of students picking "easy" topics, I usually have the opposite problem where students pick an advanced material because they find it interesting but sometimes find themselves in over their heads on the oral exam.

Concern #4 Realism: How do you know you're actually preparing students for real interviews?

As part of the refining process, I check in with a variety of stakeholders. These include alumni who are currently in graduate programs, alumni who are currently practicing engineers, practicing engineers on our advisory board who are not alumni, current students who took the course in a prior term, and faculty colleagues both within and outside of the department.

Every time I check in with stakeholders, I have received near universal positive feedback regarding 1) the fact that I incorporate oral exams, 2) how I frame the oral exams initially as calculation focused for younger students and then proposal based for older students, and 3) the questions I ask being similar to those asked in technical interviews. Practicing engineers who talk to their colleagues about my approach to oral exams have told me that their colleagues gave the same positive feedback. When I hear of a student who has recently gone through a technical interview, I reach out to them via email and ask to hear their experience in terms of the types of questions asked. I reflect on that discussion in my teaching journal to incorporate into next year's oral exam.

Concern #5 Student Comfort: What about student preference/comfort level given social anxiety?

I am committed to creating environments where students can thrive, especially in situations that are challenging. Here are suggestions based on what students have said is helpful for addressing anxiety associated with taking oral exams:

1. Create avenues for open, honest discussion about the purpose and benefits of oral exams and their anxieties surrounding it.
    a. I discuss the purpose and benefits of the oral exam at the beginning of the term, during the practice session in the final week of the course, and at the beginning of the oral exam itself.
        i. I include statements from past students about how the oral exams helped them to prepare for technical interviews. This helps tap into students' motivation by creating opportunities for authentic assessment.
        ii. I also discuss results from educational studies that show how learning best occurs when tasks are hard but not too hard (i.e., Bjork's concept of Desirable Difficulty[25]). I follow that up with a discussion of how activities in the class help prepare them for the oral exam, making the oral exam hard in that it is a new context but not too hard because they have practiced with the material the exam covers.
    b. During informal early feedback halfway through the course, I lead a discussion about how some amount of anxiety is beneficial and how too much of it can hinder us.
        i. I ask for students' feedback on what about the oral exams is giving them anxiety and together we brainstorm strategies that they think will help ease their anxiety around oral exams. These strategies have included posting questions/rubrics earlier, practicing doing oral exams with each other outside of class, bringing their favorite drink or snack to the exam, doing meditative breathing exercises right before or during the exam, etc…
2. Demonstrate what oral exams look like and allow them to practice in a low-stakes environment. If they are available, I ask students who have taken the course before to come in for the demonstration in the last week of the course.
3. Be clear about how they will be graded with rubrics posted at the same time as the questions.
4. Allow students to correct themselves during the oral exam. If a student catches their mistake on their own and corrects it, I update my notes and their grade on the rubric. I tell students this ahead of time, so they don't feel like the first thing they say is their only chance to answer.

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Appendix A: (Sophomore-Level Course Name) Oral Exam Materials

Student Instructions on Course Website

Why an oral final:

We are doing an oral final to help prepare you for situations such as technical interviews in which you will need to express your knowledge orally vs in writing.

What to expect:

I will provide a list of questions. Please have these completed before coming to the final. During the oral exam, you will come to my office and over the course of 20 minutes, I will ask you questions about how you solved the problems. I will have a list of follow up questions that I could ask you but will not be sharing those ahead of time so be prepared to explain the how and why of your solutions.
During the exam, I will evaluate you based on a rubric (see below). If you realize during the exam that you said something wrong and go back and correct yourself, I will cross out the mistake in my notes on the rubric and it will not count against your grade.

The Questions

Here are the questions that will be asked during the final exam. To study for this exam, I recommend getting together as a group and take turns asking each other the questions. There will be a whiteboard available to you so I also recommend answering the questions standing in front of a whiteboard.

Signing up for a time

Please use this link to view open times for the oral final. Email me your top three times. I will then email you a confirmation of your time. The oral final will be held in my office (office number)**.** Please let me know if you have any questions.

Rubrics

Below are the rubrics I will use for each company.
(see rubrics on subsequent pages)

Questions and Rubrics Given to Students

Before arriving for the Oral Final exam

1. ***Choose a company.***

   Your oral exam will simulate a technical interview. Choose one of the following companies that I will represent for the technical interview.
   a. Alcoa
   b. Air Liquide
   c. Dow Chemical
   d. Lebronze Alloys

2. ***Complete all problems for the company you chose.***

   Have all problems completed by the time you come for the oral exam.

   You will need to look up all information needed to complete the problems.

What to bring to the Oral Final exam:

1. All completed problems.

2. Data and figures you used to complete the problems.

<u>Alcoa Interview Questions:</u>

Problem 1:

a) In what engineering application would you propose using pure Aluminum? Why is it ideal for that application?

b) Design a process to produce pure Aluminum from bauxite ore (Al_2O_3). Include justification for all design choices. Your furnace can handle temperatures between 200-2000^oC.

c) What are the economic, social, and political (i.e., regulations) factors that influenced your design choices? How does your design address those factors?

Problem 2:

a) Alcoa wants to make a new Al-based eutectic alloy. How would you determine whether the alloy will form a eutectic phase?

b) Calculate the Al-Si phase diagram, its eutectic temperature, and its eutectic composition.

Problem 3:

a) Alcoa manufactures Aluminum and Aluminum-based alloys via casting. What is the thermodynamically stable crystal size if we cast the Aluminum at 550^oC?

b) Would sand casting or die casting reduce the amount of undercooling required for solidification?

c) Alcoa also wants to get into making Aluminum coatings using the evaporation process. Our techs set the Aluminum effusion cell's temperature to 700^oC in a 1 mTorr atmosphere. However, when the process was finished, we found no Aluminum coating on the substrate. What went wrong and how would you propose fixing the issue?

Alcoa Rubric

Categories	Meets expectations. (20 points)	Mostly meets expectations. (15 points)	Partially meets expectations. (10 points)	Unsatisfactory (5 points)	Total
Prepared for oral exam.	All three 1. Completed all problems. 2. All data and information used to solve problems come from reputable sources. 3. When asking conceptual questions, looked at notes sparingly. Did not rely on them.	Two of three 1. Completed all problems. 2. All data and information used to solve problems come from reputable sources. 3. When asking conceptual questions, looked at notes sparingly. Did not rely on them.	One of three 1. Completed all problems. 2. All data and information used to solve problems come from reputable sources. 3. When asking conceptual questions, looked at notes sparingly. Did not rely on them.	Zero of three 1. Completed all problems. 2. All data and information used to solve problems come from reputable sources. 3. When asking conceptual questions, looked at notes sparingly. Did not rely on them.	
Problem 1	All four 1. Explains why Aluminum is ideal for their chosen application. 2. Includes all relevant design choices and justification for each when asked. 3. Identified at least one economic, social, and political factor that influenced their design AND explained how their design accommodates those factors. 4. Satisfactorily answers follow up questions.	Three of four 1. Explains why Aluminum is ideal for their chosen application. 2. Includes all relevant design choices and justification for each when asked. 3. Identified at least one economic, social, and political factor that influenced their design AND explained how their design accommodates those factors. 4. Satisfactorily answers follow up questions.	Two of four 1. Explains why Aluminum is ideal for their chosen application. 2. Includes all relevant design choices and justification for each when asked. 3. Identified at least one economic, social, and political factor that influenced their design AND explained how their design accommodates those factors. 4. Satisfactorily answers follow up questions.	One of four 1. Explains why Aluminum is ideal for their chosen application. 2. Includes all relevant design choices and justification for each when asked. 3. Identified at least one economic, social, and political factor that influenced their design AND explained how their design accommodates those factors. 4. Satisfactorily answers follow up questions.	
Problem 2	All four 1. Applies appropriate course concepts to determine whether a eutectic phase will form. 2. Applies appropriate equations to calculate the eutectic composition. 3. Applies appropriate equations to calculate the eutectic temperature. 4. Satisfactorily answers follow up questions.	Three of four 1. Applies appropriate course concepts to determine whether a eutectic phase will form. 2. Applies appropriate equations to calculate the eutectic composition. 3. Applies appropriate equations to calculate the eutectic temperature. 4. Satisfactorily answers follow up questions.	Two of four 1. Applies appropriate course concepts to determine whether a eutectic phase will form. 2. Applies appropriate equations to calculate the eutectic composition. 3. Applies appropriate equations to calculate the eutectic temperature. 4. Satisfactorily answers follow up questions.	One of four 1. Applies appropriate course concepts to determine whether a eutectic phase will form. 2. Applies appropriate equations to calculate the eutectic composition. 3. Applies appropriate equations to calculate the eutectic temperature. 4. Satisfactorily answers follow up questions.	

Problem 3	All four 1. Appropriately uses equations to calculate the thermodynamically stable crystal size. 2. Appropriately uses thermodynamic concepts to select casting type. 3. Appropriately uses thermodynamic concepts to identify the problem and the solution. 4. Satisfactorily answers follow up questions.	Three of four 1. Appropriately uses equations to calculate the thermodynamically stable crystal size. 2. Appropriately uses thermodynamic concepts to select casting type. 3. Appropriately uses thermodynamic concepts to identify the problem and the solution. 4. Satisfactorily answers follow up questions.	Two of four 1. Appropriately uses equations to calculate the thermodynamically stable crystal size. 2. Appropriately uses thermodynamic concepts to select casting type. 3. Appropriately uses thermodynamic concepts to identify the problem and the solution. 4. Satisfactorily answers follow up questions.	One of four 1. Appropriately uses equations to calculate the thermodynamically stable crystal size. 2. Appropriately uses thermodynamic concepts to select casting type. 3. Appropriately uses thermodynamic concepts to identify the problem and the solution. 4. Satisfactorily answers follow up questions.	
Lessons learned and importance to your career.	All three 1. Relates what they learned to course concepts, industrial standards, industrial trends, and/or current academic research. 2. Explains how what they learned will be useful in their future career. 3. Student identifies more than just a single fact. Additionally, student explains why the thing they learned is important.	Two of three 1. Relates what they learned to course concepts, industrial standards, industrial trends, and/or current academic research. 2. Explains how what they learned will be useful in their future career. 3. Student identifies more than just a single fact. Additionally, student explains why the thing they learned is important.	One of three 1. Relates what they learned to course concepts, industrial standards, industrial trends, and/or current academic research. 2. Explains how what they learned will be useful in their future career. 3. Student identifies more than just a single fact. Additionally, student explains why the thing they learned is important.	Only lists individual facts. Does not relate them to course concepts, industrial standards, industrial trends, or academic research.	
Critical thinking. (x1.5) Note: this category only applies when instructors ask the student harder questions until they do not know the answer right away.	Student responds with a detailed plan for how they would find the answer. OR Student appropriately applies course concepts to reason out an answer.	Student responds with a general plan for how they would find the answer. Does not give examples of where they would look for information. OR Student appropriately applies course concepts to reason out an answer. However, they get some of the concepts incorrect.	Student responds with a vague plan for how they would find the answer. It's not clear what the student's plan is. OR Student inappropriately applies course concepts to reason out an answer.	Student does not apply course concepts to reason out an answer nor explain how they would find the answer.	
Clarity in communicating knowledge and problem solving.	All three 1. Student answers the question that was asked. 2. Students' answers are concise. 3. Uses appropriate data or figures when explaining their solutions.	Two of three 1. Student answers the question that was asked. 2. Students' answers are concise. 3. Uses appropriate data or figures when explaining their solutions.	One of three 1. Student answers the question that was asked. 2. Students' answers are concise. 3. Uses appropriate data or figures when explaining their solutions.	Zero of three 1. Student answers the question that was asked. 2. Students' answers are concise. 3. Uses appropriate data or figures when explaining their solutions.	
Total (150 points)					

Air Liquide Interview Questions:

Choose one of the gases that the company makes for problems 1-3.

Problem 1:

a) In what engineering application would you propose using this gas? Why is it ideal for that application?

b) What are the economic, social, and political (i.e., regulations) impacts of sourcing, making, or using the gas on society?

Problem 2:

a) Propose a reaction to make the gas.

b) What temperature and pressure would you run the reaction at to maximize the amount of product gas created?

c) How would you measure the enthalpy and entropy of the reaction you used to make the gas?

Problem 3:

a) Design a process to liquify the gas. The whole design needs to fit in a system no larger than 40 m^3. Note: The only calculations I need to see are the ones that cause temperature changes due to changes in volume and pressure.

b) We want to store the liquified gas in a pressurized tank. What pressure would we have to store the gas under to keep it a liquid at room temperature?

Air Liquide Rubric

Categories	Meets expectations. (20 points)	Mostly meets expectations. (15 points)	Partially meets expectations. (10 points)	Unsatisfactory (5 points)	Total
Prepared for oral exam.	All three 1. Completed all problems. 2. All data and information used to solve problems come from reputable sources. 3. When asking conceptual questions, looked at notes sparingly. Did not rely on them.	Two of three 1. Completed all problems. 2. All data and information used to solve problems come from reputable sources. 3. When asking conceptual questions, looked at notes sparingly. Did not rely on them.	One of three 1. Completed all problems. 2. All data and information used to solve problems come from reputable sources. 3. When asking conceptual questions, looked at notes sparingly. Did not rely on them.	Zero of three 1. Completed all problems. 2. All data and information used to solve problems come from reputable sources. 3. When asking conceptual questions, looked at notes sparingly. Did not rely on them.	
Problem 1	All four 1. Describes the role their gas plays in the engineering application. 2. Explains why the gas chosen is ideal for their chosen application over other gases. 3. Identified at least one economic, social, and political impact of sourcing, manufacturing, or using the gas on society. 4. Satisfactorily answers follow up questions.	Three of four 1. Describes the role their gas plays in the engineering application. 2. Explains why the gas chosen is ideal for their chosen application over other gases. 3. Identified at least one economic, social, and political impact of sourcing, manufacturing, or using the gas on society. 4. Satisfactorily answers follow up questions.	Two of four 1. Describes the role their gas plays in the engineering application. 2. Explains why the gas chosen is ideal for their chosen application over other gases. 3. Identified at least one economic, social, and political impact of sourcing, manufacturing, or using the gas on society. 4. Satisfactorily answers follow up questions.	One of four 1. Describes the role their gas plays in the engineering application. 2. Explains why the gas chosen is ideal for their chosen application over other gases. 3. Identified at least one economic, social, and political impact of sourcing, manufacturing, or using the gas on society. 4. Satisfactorily answers follow up questions.	
Problem 2	All four 1. Describes the reaction used to make the gas. 2. Applies appropriate equations and thermodynamic concepts to calculate the temperature and pressure needed to maximize gas yield. 3. Explains how to measure the enthalpy and entropy of the reaction they proposed. 4. Satisfactorily answers follow up questions.	Three of four 1. Describes the reaction used to make the gas. 2. Applies appropriate equations and thermodynamic concepts to calculate the temperature and pressure needed to maximize gas yield. 3. Explains how to measure the enthalpy and entropy of the reaction they proposed. 4. Satisfactorily answers follow up questions.	Two of four 1. Describes the reaction used to make the gas. 2. Applies appropriate equations and thermodynamic concepts to calculate the temperature and pressure needed to maximize gas yield. 3. Explains how to measure the enthalpy and entropy of the reaction they proposed. 4. Satisfactorily answers follow up questions.	One of four 1. Describes the reaction used to make the gas. 2. Applies appropriate equations and thermodynamic concepts to calculate the temperature and pressure needed to maximize gas yield. 3. Explains how to measure the enthalpy and entropy of the reaction they proposed. 4. Satisfactorily answers follow up questions.	

Problem 3	All four 1. Appropriately uses thermodynamic concepts to design a process to liquify the gas. 2. Applies thermodynamic equations to calculate the design parameters. 3. Appropriately uses thermodynamic concepts or equations to determine the pressure needed to store the gas. 4. Satisfactorily answers follow up questions.	Three of four 1. Appropriately uses thermodynamic concepts to design a process to liquify the gas. 2. Applies thermodynamic equations to calculate the design parameters. 3. Appropriately uses thermodynamic concepts or equations to determine the pressure needed to store the gas. 4. Satisfactorily answers follow up questions.	Two of four 1. Appropriately uses thermodynamic concepts to design a process to liquify the gas. 2. Applies thermodynamic equations to calculate the design parameters. 3. Appropriately uses thermodynamic concepts or equations to determine the pressure needed to store the gas. 4. Satisfactorily answers follow up questions.	One of four 1. Appropriately uses thermodynamic concepts to design a process to liquify the gas. 2. Applies thermodynamic equations to calculate the design parameters. 3. Appropriately uses thermodynamic concepts or equations to determine the pressure needed to store the gas. 4. Satisfactorily answers follow up questions.	
Lessons learned and importance to your career.	All three 1. Relates what they learned to course concepts, industrial standards, industrial trends, and/or current academic research. 2. Explains how what they learned will be useful in their future career. 3. Student identifies more than just a single fact. Additionally, student explains why the thing they learned is important.	Two of three 1. Relates what they learned to course concepts, industrial standards, industrial trends, and/or current academic research. 2. Explains how what they learned will be useful in their future career. 3. Student identifies more than just a single fact. Additionally, student explains why the thing they learned is important.	One of three 1. Relates what they learned to course concepts, industrial standards, industrial trends, and/or current academic research. 2. Explains how what they learned will be useful in their future career. 3. Student identifies more than just a single fact. Additionally, student explains why the thing they learned is important.	Only lists individual facts. Does not relate them to course concepts, industrial standards, industrial trends, or academic research.	
Critical thinking. (x1.5) Note: this category only applies when instructors ask the student harder questions until they do not know the answer right away.	Student responds with a detailed plan for how they would find the answer. OR Student appropriately applies course concepts to reason out an answer.	Student responds with a general plan for how they would find the answer. Does not give examples of where they would look for information. OR Student appropriately applies course concepts to reason out an answer. However, they get some of the concepts incorrect.	Student responds with a vague plan for how they would find the answer. It's not clear what the student's plan is. OR Student inappropriately applies course concepts to reason out an answer.	Student does not apply course concepts to reason out an answer nor explain how they would find the answer.	
Clarity in communicating knowledge and problem solving.	All three 1. Student answers the question that was asked. 2. Students' answers are concise. 3. Uses appropriate data or figures when explaining their solutions.	Two of three 1. Student answers the question that was asked. 2. Students' answers are concise. 3. Uses appropriate data or figures when explaining their solutions.	One of three 1. Student answers the question that was asked. 2. Students' answers are concise. 3. Uses appropriate data or figures when explaining their solutions.	Zero of three 1. Student answers the question that was asked. 2. Students' answers are concise. 3. Uses appropriate data or figures when explaining their solutions.	
Total (150 points)					

Dow Chemical Interview Questions:

Problem 1:

a) In what engineering application would you propose using the solvent 1-proponal? Why is it ideal for that application?

b) What are the economic, social, and political (i.e., regulations) impacts of sourcing, making, or using 1-proponal on society?

Problem 2:

a) A client has requested 1 liter of a 1-propanol-water solution with a 1-propanol mol fraction of 0.80. You have available stock solutions with a 1-propanol mol fraction of 0.50. Design a process to produce the client's desired amount and purity of the 1-propanol solution.

b) Could you use the same process if the stock solutions had a 1-propanol mol fraction of 0.3? If so, explain why. If not, explain how you would modify the design. Be specific on what the modifications are. No calculations required.

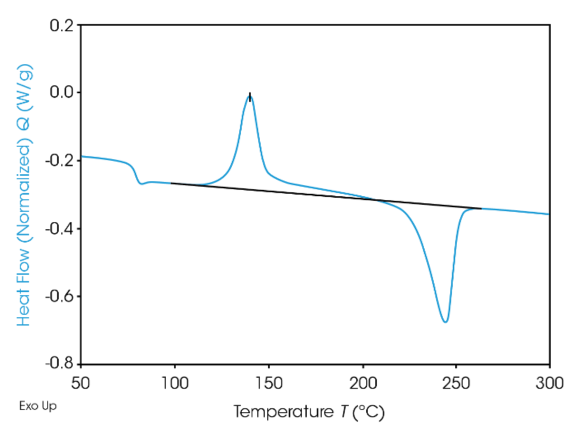
Problem 3:

a) Dow chemical is also investigating new methods to produce chemicals that are pre-cursors to polymers in applications such as adhesives, sporting equipment, and show soles. The process of converting the pre-cursors to polymers is called polymerization. How would you measure the enthalpy of polymerization?

b) Your coworker found some PET polymer samples. They'd like to use it in a project and have asked you to characterize the polymer's properties and processing history. You run a sample in the DSC and get the following heating curve. Endothermic peaks point down. You use a heating rate of 10°C/min.

Calculate the following properties for your coworker:

- Glass transition temperature
- Cold crystallization temperature (if it cold crystallizes)
- Melting temperature
- Specific heat capacity before and after the glass transition.
- Percent crystallinity. If the sample exhibits cold crystallization, determine the percent crystallinity before and after cold crystallization.



Dow Chemical Rubric

Categories	Meets expectations. (20 points)	Mostly meets expectations. (15 points)	Partially meets expectations. (10 points)	Unsatisfactory (5 points)	Total
Prepared for oral exam.	All three 1. Completed all problems. 2. All data and information used to solve problems come from reputable sources. 3. When asking conceptual questions, looked at notes sparingly. Did not rely on them.	Two of three 1. Completed all problems. 2. All data and information used to solve problems come from reputable sources. 3. When asking conceptual questions, looked at notes sparingly. Did not rely on them.	One of three 1. Completed all problems. 2. All data and information used to solve problems come from reputable sources. 3. When asking conceptual questions, looked at notes sparingly. Did not rely on them.	Zero of three 1. Completed all problems. 2. All data and information used to solve problems come from reputable sources. 3. When asking conceptual questions, looked at notes sparingly. Did not rely on them.	
Problem 1	All four 1. Describes the role that 1-proponal plays in the engineering application. 2. Explains why 1-proponal is ideal for their chosen application over other solvents. 3. Identified at least one economic, social, and political impact of sourcing, manufacturing, or using 1-proponal on society. 4. Satisfactorily answers follow up questions.	Three of four 1. Describes the role that 1-proponal plays in the engineering application. 2. Explains why 1-proponal is ideal for their chosen application over other solvents. 3. Identified at least one economic, social, and political impact of sourcing, manufacturing, or using 1-proponal on society. 4. Satisfactorily answers follow up questions.	Two of four 1. Describes the role that 1-proponal plays in the engineering application. 2. Explains why 1-proponal is ideal for their chosen application over other solvents. 3. Identified at least one economic, social, and political impact of sourcing, manufacturing, or using 1-proponal on society. 4. Satisfactorily answers follow up questions.	One of four 1. Describes the role that 1-proponal plays in the engineering application. 2. Explains why 1-proponal is ideal for their chosen application over other solvents. 3. Identified at least one economic, social, and political impact of sourcing, manufacturing, or using 1-proponal on society. 4. Satisfactorily answers follow up questions.	
Problem 2	All four 1. Appropriately uses thermodynamic concepts to design the distillation process. 2. Applies thermodynamic equations to calculate the relevant design parameters. 3. Appropriately uses thermodynamic concepts to choose required modifications or explain why modifications are not needed. 4. Satisfactorily answers follow up questions.	Three of four 1. Appropriately uses thermodynamic concepts to design the distillation process. 2. Applies thermodynamic equations to calculate the relevant design parameters. 3. Appropriately uses thermodynamic concepts to choose required modifications or explain why modifications are not needed. 4. Satisfactorily answers follow up questions.	Two of four 1. Appropriately uses thermodynamic concepts to design the distillation process. 2. Applies thermodynamic equations to calculate the relevant design parameters. 3. Appropriately uses thermodynamic concepts to choose required modifications or explain why modifications are not needed. 4. Satisfactorily answers follow up questions.	One of four 1. Appropriately uses thermodynamic concepts to design the distillation process. 2. Applies thermodynamic equations to calculate the relevant design parameters. 3. Appropriately uses thermodynamic concepts to choose required modifications or explain why modifications are not needed. 4. Satisfactorily answers follow up questions.	

Problem 3	All four 1. Appropriately uses thermodynamic concepts to explain how to measure the enthalpy of polymerization. 2. Appropriately uses thermodynamic concepts to identify where properties are present on the DSC curve. 3. Applies data analysis to the DSC data to calculate the requested properties. 4. Satisfactorily answers follow up questions.	Three of four 1. Appropriately uses thermodynamic concepts to explain how to measure the enthalpy of polymerization. 2. Appropriately uses thermodynamic concepts to identify where properties are present on the DSC curve. 3. Applies data analysis to the DSC data to calculate the requested properties. 4. Satisfactorily answers follow up questions.	Two of four 1. Appropriately uses thermodynamic concepts to explain how to measure the enthalpy of polymerization. 2. Appropriately uses thermodynamic concepts to identify where properties are present on the DSC curve. 3. Applies data analysis to the DSC data to calculate the requested properties. 4. Satisfactorily answers follow up questions.	One of four 1. Appropriately uses thermodynamic concepts to explain how to measure the enthalpy of polymerization. 2. Appropriately uses thermodynamic concepts to identify where properties are present on the DSC curve. 3. Applies data analysis to the DSC data to calculate the requested properties. 4. Satisfactorily answers follow up questions.	
Lessons learned and importance to your career.	All three 1. Relates what they learned to course concepts, industrial standards, industrial trends, and/or current academic research. 2. Explains how what they learned will be useful in their future career. 3. Student identifies more than just a single fact. Additionally, student explains why the thing they learned is important.	Two of three 1. Relates what they learned to course concepts, industrial standards, industrial trends, and/or current academic research. 2. Explains how what they learned will be useful in their future career. 3. Student identifies more than just a single fact. Additionally, student explains why the thing they learned is important.	One of three 1. Relates what they learned to course concepts, industrial standards, industrial trends, and/or current academic research. 2. Explains how what they learned will be useful in their future career. 3. Student identifies more than just a single fact. Additionally, student explains why the thing they learned is important.	Only lists individual facts. Does not relate them to course concepts, industrial standards, industrial trends, or academic research.	
Critical thinking. (x1.5) Note: this category only applies when instructors ask the student harder questions until they do not know the answer right away.	Student responds with a detailed plan for how they would find the answer. OR Student appropriately applies course concepts to reason out an answer.	Student responds with a general plan for how they would find the answer. Does not give examples of where they would look for information. OR Student appropriately applies course concepts to reason out an answer. However, they get some of the concepts incorrect.	Student responds with a vague plan for how they would find the answer. It's not clear what the student's plan is. OR Student inappropriately applies course concepts to reason out an answer.	Student does not apply course concepts to reason out an answer nor explain how they would find the answer.	
Clarity in communicating knowledge and problem solving.	All three 1. Student answers the question that was asked. 2. Students' answers are concise. 3. Uses appropriate data or figures when explaining their solutions.	Two of three 1. Student answers the question that was asked. 2. Students' answers are concise. 3. Uses appropriate data or figures when explaining their solutions.	One of three 1. Student answers the question that was asked. 2. Students' answers are concise. 3. Uses appropriate data or figures when explaining their solutions.	Zero of three 1. Student answers the question that was asked. 2. Students' answers are concise. 3. Uses appropriate data or figures when explaining their solutions.	
Total (150 points)					

Lebronze Alloys Interview Questions:

Problem 1:

a) In what engineering application would you propose using Cu-Ni spinodal alloys? Why is it ideal for that application?

b) What are the economic, social, and political (i.e., regulations) impacts of sourcing, making, or using Cu-Ni spinodal alloys?

Problem 2:

a) Calculate the Cu-Ni phase diagram from 0°C to 1600°C.

b) Estimate the value of the solid solution interaction parameter.

c) Does the solid solution obey ideal solution behavior, regular solution behavior, or neither?

Problem 3:

a) Vacancies can strengthen your Cu-Ni metal alloys. Propose a way to measure the equilibrium vacancy defect concentration.

b) Estimate the enthalpy of vacancy formation for a Cu-Ni alloy with $x_{Ni} = 0.25$.

c) Calculate the vacancy concentration for a sample heated to 500°C.

d) Propose a way to achieve the vacancy concentration in part c while the sample is at room temperature.

Lebronze Alloys Interview Questions

Categories	Meets expectations. (20 points)	Mostly meets expectations. (15 points)	Partially meets expectations. (10 points)	Unsatisfactory (5 points)	Total
Prepared for oral exam.	All three 1. Completed all problems. 2. All data and information used to solve problems come from reputable sources. 3. When asking conceptual questions, looked at notes sparingly. Did not rely on them.	Two of three 1. Completed all problems. 2. All data and information used to solve problems come from reputable sources. 3. When asking conceptual questions, looked at notes sparingly. Did not rely on them.	One of three 1. Completed all problems. 2. All data and information used to solve problems come from reputable sources. 3. When asking conceptual questions, looked at notes sparingly. Did not rely on them.	Zero of three 1. Completed all problems. 2. All data and information used to solve problems come from reputable sources. 3. When asking conceptual questions, looked at notes sparingly. Did not rely on them.	
Problem 1	All three 1. Identifies a relevant engineering application for Cu-Ni spinodal alloys based on structure-property relationships of spinodal alloys. 2. Identified at least one economic, social, and political impact of sourcing, making, or using Cu-Ni spinodal alloys. 3. Satisfactorily answers follow up questions.	Two of three 1. Identifies a relevant engineering application for Cu-Ni spinodal alloys based on structure-property relationships of spinodal alloys. 2. Identified at least one economic, social, and political impact of sourcing, making, or using Cu-Ni spinodal alloys. 3. Satisfactorily answers follow up questions.	One of three 1. Identifies a relevant engineering application for Cu-Ni spinodal alloys based on structure-property relationships of spinodal alloys. 2. Identified at least one economic, social, and political impact of sourcing, making, or using Cu-Ni spinodal alloys. 3. Satisfactorily answers follow up questions.	Zero of three 1. Identifies a relevant engineering application for Cu-Ni spinodal alloys based on structure-property relationships of spinodal alloys. 2. Identified at least one economic, social, and political impact of sourcing, making, or using Cu-Ni spinodal alloys. 3. Satisfactorily answers follow up questions.	
Problem 2	All four 1. Applies appropriate course concepts when explaining how they calculated the phase diagram. 2. Accurately estimates the interaction parameter. Uses appropriate concepts and equations. 3. Applies appropriate concepts when explaining whether the system shows ideal solution or regular solution behavior. 4. Satisfactorily answers follow up questions.	Three of four 1. Applies appropriate course concepts when explaining how they calculated the phase diagram. 2. Accurately estimates the interaction parameter. Uses appropriate concepts and equations. 3. Applies appropriate concepts when explaining whether the system shows ideal solution or regular solution behavior. 4. Satisfactorily answers follow up questions.	Two of four 1. Applies appropriate course concepts when explaining how they calculated the phase diagram. 2. Accurately estimates the interaction parameter. Uses appropriate concepts and equations. 3. Applies appropriate concepts when explaining whether the system shows ideal solution or regular solution behavior. 4. Satisfactorily answers follow up questions.	One of four 1. Applies appropriate course concepts when explaining how they calculated the phase diagram. 2. Accurately estimates the interaction parameter. Uses appropriate concepts and equations. 3. Applies appropriate concepts when explaining whether the system shows ideal solution or regular solution behavior. 4. Satisfactorily answers follow up questions.	
Problem 3	All four 1. Identifies an appropriate way to measure vacancy concentrations. Justifies why that technique over others. 2. Appropriately uses concepts when estimating the enthalpy of vacancy	Three of four 1. Identifies an appropriate way to measure vacancy concentrations. Justifies why that technique over others.	Two of four 1. Identifies an appropriate way to measure vacancy concentrations. Justifies why that technique over others.	One of four 1. Identifies an appropriate way to measure vacancy concentrations. Justifies why that technique over others.	

	formation and calculating the vacancy concentration. 3. Identifies an appropriate way to achieve the vacancy concentration at 500ºC for a sample at room temperature. Appropriately uses concepts to justify their approach. 4. Satisfactorily answers follow up questions.	2. Appropriately uses concepts when estimating the enthalpy of vacancy formation and calculating the vacancy concentration. 3. Identifies an appropriate way to achieve the vacancy concentration at 500ºC for a sample at room temperature. Appropriately uses concepts to justify their approach. 4. Satisfactorily answers follow up questions.	2. Appropriately uses concepts when estimating the enthalpy of vacancy formation and calculating the vacancy concentration. 3. Identifies an appropriate way to achieve the vacancy concentration at 500ºC for a sample at room temperature. Appropriately uses concepts to justify their approach. 4. Satisfactorily answers follow up questions.	2. Appropriately uses concepts when estimating the enthalpy of vacancy formation and calculating the vacancy concentration. 3. Identifies an appropriate way to achieve the vacancy concentration at 500ºC for a sample at room temperature. Appropriately uses concepts to justify their approach. 4. Satisfactorily answers follow up questions.	
Lessons learned and importance to your career.	All three 1. Relates what they learned to course concepts, industrial standards, industrial trends, and/or current academic research. 2. Explains how what they learned will be useful in their future career. 3. Student identifies more than just a single fact. Additionally, student explains why the thing they learned is important.	Two of three 1. Relates what they learned to course concepts, industrial standards, industrial trends, and/or current academic research. 2. Explains how what they learned will be useful in their future career. 3. Student identifies more than just a single fact. Additionally, student explains why the thing they learned is important.	One of three 1. Relates what they learned to course concepts, industrial standards, industrial trends, and/or current academic research. 2. Explains how what they learned will be useful in their future career. 3. Student identifies more than just a single fact. Additionally, student explains why the thing they learned is important.	Only lists individual facts. Does not relate them to course concepts, industrial standards, industrial trends, or academic research.	
Critical thinking. (x1.5) Note: this category only applies when instructors ask the student harder questions until they do not know the answer right away.	Student responds with a detailed plan for how they would find the answer. OR Student appropriately applies course concepts to reason out an answer.	Student responds with a general plan for how they would find the answer. Does not give examples of where they would look for information. OR Student appropriately applies course concepts to reason out an answer. However, they get some of the concepts incorrect.	Student responds with a vague plan for how they would find the answer. It's not clear what the student's plan is. OR Student inappropriately applies course concepts to reason out an answer.	Student does not apply course concepts to reason out an answer nor explain how they would find the answer.	
Clarity in communicating knowledge and problem solving.	All three 1. Student answers the question that was asked. 2. Students' answers are concise. 3. Uses appropriate data or figures when explaining their solutions.	Two of three 1. Student answers the question that was asked. 2. Students' answers are concise. 3. Uses appropriate data or figures when explaining their solutions.	One of three 1. Student answers the question that was asked. 2. Students' answers are concise. 3. Uses appropriate data or figures when explaining their solutions.	Zero of three 1. Student answers the question that was asked. 2. Students' answers are concise. 3. Uses appropriate data or figures when explaining their solutions.	
Total (150 points)					

Appendix B: (Junior-Level Course Name) Oral Exam Materials

Student Instructions on Course Website

Oral Final Exam

In industry and academia, you are expected to express your knowledge orally. This could be in client meetings, team meetings, presentations, interviews, etc... To help you practice this skill and evaluate your course knowledge, we will do an oral exam for the final exam.

Please do the following before you come to the oral exam:

1. Select an electronic device that you are interested in and benefits society.
2. Select a material that you believe will improve the function of the device over the material currently used.
3. Investigate the structure-property-processing relationship for that material.
4. Investigate the societal importance of the material and the device it will be used in. How does it impact people?
5. Compare your findings to the material currently used.

How I will evaluate you:

I will be using a rubric for the exam. The rubric will have the following categories:

1. Structure-Properties-Processing relationship: Do you describe the relationship between structure, properties, and processing that leads to the material's performance?
2. Performance: Do you explain how the performance of the material is evaluated? How does this material perform compared to the standard material used? Do you explain why the materials perform differently?
3. Societal Importance: Do you explain how the device benefits society? Do you explain how switching to this material from the standard material used would impact people, positively or negatively?
4. Material selection: Would you recommend companies switch to your material over the one currently used now? In the next 5 years? In the next 20? Ever?
5. What did you learn: Do you relate what you learned in your research to course concepts, industry standards, industry trends, and/or current academic research?
6. Follow up questions: At some point in the oral exam, I will ask you questions until you do not know the answer right away. Do you demonstrate problem solving by drawing conclusions from what you do know?

Note 1: Many of you know how expressive I am. During the oral final, I will maintain a neutral face. This is to ensure that I do not influence your answers in any way. You will need to be confident in your answers.

Signing up for a time

Please use this link to view open times for the oral final. Email me your top three times. I will then email you a confirmation of your time. The oral final will be held in my office. Please let me know if you have any questions.

Electronic Materials Course Oral Exam Rubric

Categories	Meets expectations. (10 points)	Mostly meets expectations. (7 points)	Partially meets expectations. (5 points)	Unsatisfactory (1 point)	Total
Structure-properties-processing relationship (X2) **Follow up question:** How would you predict the effect of [insert processing technique here] on your material's structure or properties?	All three 1. Gives one example of how the relationship between structure-properties-processing leads to the material's performance in the device. 2. Gives second example of how the relationship between structure-properties-processing leads to the material's performance in the device. 3. Student appropriately uses course concepts and equations (if needed) to answer follow-up question.	Two of three 1. Gives one example of how the relationship between structure-properties-processing leads to the material's performance in the device. 2. Gives second example of how the relationship between structure-properties-processing leads to the material's performance in the device. 3. Student appropriately uses course concepts and equations (if needed) to answer follow-up question.	One of three 1. Gives one example of how the relationship between structure-properties-processing leads to the material's performance in the device. 2. Gives second example of how the relationship between structure-properties-processing leads to the material's performance in the device. 3. Student appropriately uses course concepts and equations (if needed) to answer follow-up question.	Discusses the material's structure, properties, and/or processing but not their relationship to each other. AND Does not explain how these relate to performance.	
Performance **Follow up question:** How and why does your material perform differently than the industry standard option?	All three 1. Identifies two performance metrics of the material and how they are measured. 2. Compares their material's performance with industry-standard materials. 3. Student appropriately uses course concepts and equations (if needed) to answer follow-up question.	Two of three 1. Identifies two performance metrics of the material and how they are measured. 2. Compares their material's performance with industry-standard materials. 3. Student appropriately uses course concepts and equations (if needed) to answer follow-up question.	One of three 1. Identifies two performance metrics of the material and how they are measured. 2. Compares their material's performance with industry-standard materials. 3. Student appropriately uses course concepts and equations (if needed) to answer follow-up question.	Does not identify performance metrics nor explain how they are measured. Does not compare their material's performance with industry-standard materials.	
Societal importance (X2) **Follow up question:** What do you think will be the impact on [insert a group of people the student did not initially mention] if industry uses your material?	All three 1. Use specific details from their pre-exam research to explain the positive and negative impacts of using their proposed material. 2. Identifies the specific group(s) impacted and how they are impacted. 3. Student answers follow up question using specific details from their pre-exam research.	Two of three 1. Use specific details from their pre-exam research to explain the positive and negative impacts of using their proposed material. 2. Identifies the specific group(s) impacted and how they are impacted. 3. Student answers follow up question using specific details from their pre-exam research.	One of three 1. Use specific details from their pre-exam research to explain the positive and negative impacts of using their proposed material. 2. Identifies the specific group(s) impacted and how they are impacted. 3. Student answers follow up question using specific details from their pre-exam research.	Does not identify nor explain the impacts of their proposed material on society. Does not identify the group(s) impacted and how they are impacted.	

Material selection (X2) **Follow up question:** How do you think your material will impact the industry?	All three 1. Identifies whether material is a good choice to replace the industry standard material. 2. Identifies what would need to happen for material to feasibly be adopted by industry. 3. Student appropriately uses industry trends and course concepts as part of explanation.	Two of three 1. Identifies whether material is a good choice to replace the industry standard material. 2. Identifies what would need to happen for material to feasibly be adopted by industry. 3. Student appropriately uses industry trends and course concepts as part of explanation.	One of three 1. Identifies whether material is a good choice to replace the industry standard material. 2. Identifies what would need to happen for material to feasibly be adopted by industry. 3. Student appropriately uses industry trends and course concepts as part of explanation.	Does not discuss whether companies should switch to the new material. OR Does not explain why companies should or should not switch to the new material.	
What did you learn? **Follow up question:** What was the most important thing you learned?	All three 1. Relates what they learned to course concepts, industrial standards, industrial trends, and/or current academic research. 2. Explains how what they learned will be useful in their future career. 3. Student appropriately uses course concepts and their pre-exam research to justify their answer to the follow up questions.	Two of three 1. Relates what they learned to course concepts, industrial standards, industrial trends, and/or current academic research. 2. Explains how what they learned will be useful in their future career. 3. Student appropriately uses course concepts and their pre-exam research to justify their answer to the follow up questions.	One of three 1. Relates what they learned to course concepts, industrial standards, industrial trends, and/or current academic research. 2. Explains how what they learned will be useful in their future career. 3. Student appropriately uses course concepts and their pre-exam research to justify their answer to the follow up questions.	Only lists individual facts. Does not relate them to course concepts, industrial standards, industrial trends, or academic research.	
Critical thinking (X2) Note: this category only applies when instructors ask the student harder questions until they do not know the answer right away.	Student responds with a detailed plan for how they would find the answer. OR Student appropriately applies course concepts to reason out an answer.	Student responds with a general plan for how they would find the answer. Does not give examples of where they would look for information. OR Student appropriately applies course concepts to reason out an answer. However, they get some of the concepts incorrect.	Student responds with a vague plan for how they would find the answer. It’s not clear what the student’s plan is. OR Student inappropriately applies course concepts to reason out an answer.	Student does not apply course concepts to reason out an answer nor explain how they would find the answer.	
Total (100 points)					