AC 2011-177: IMPLEMENTING PROBLEM BASED LEARNING IN MATERIALS SCIENCE

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Implementing Problem Based Learning in Materials Science

Problem solving is the primary intellectual activity of mechanical engineers. Practicing engineers are hired, retained, and rewarded for solving problems Jonassen, Strobel, & Lee, 2006). Therefore, enhancing problem-solving skills is essential for preparing mechanical engineering students for the workplace. Workplace engineering problems are substantively different from the kinds of problems that engineering students most often solve in the classroom. They are ill structured and complex, because they possess conflicting goals, multiple solution methods, non-engineering success standards, non-engineering constraints, unanticipated problems, distributed knowledge, collaborative activity systems, required experience, and multiple forms of problem representation. Therefore, learning to solve classroom problems does not adequately prepare engineering students to solve workplace problems.

Based on those assumptions, we have designed, implemented, and are now testing a problem-based learning version of a materials science course in the mechanical engineering curriculum. Materials science was chosen because it is the first course in the mechanical engineering sequence, and because virtually every mechanical engineering problem involves materials selection or materials troubleshooting elements. Before describing the course and the results of an initial trial implementation, we describe principles of problem-based learning (PBL).

Practices and principles of problem-based learning

Preparing for professional practice in any discipline requires that students learn to think like successful practitioners in that field. PBL is an instructional strategy in which a unit, course, or curriculum is organized around problems authentic to practice rather than subject mater content. Rather than studying concepts, principles and theories and later applying them to problems, learning is organized and oriented by the problems, so the problems come first. Students work in groups on a given problem and are given the responsibility to determine and carry out what they need to learn and do in order to solve that problem with the assistance of faculty. PBL programs generally exhibit the following characteristics:

- Student-centered learning
- Collaborative learning
- Instructors as facilitators
- Self-directed learning.

In order to succeed in a PBL setting, learners must acquire skills in the problem-solving process as well as the content of the course in which the problem is situated. Unfortunately, first-time PBL students often struggle with how to identify and learn what they need to know to solve a problem without the familiar context of instructor lectures preceding the assignment of the problem (Vardi & Ciccarelli, 2008).

PBL implementations in engineering disciplines

In addition to the challenges faced by novice problem-based learners, there may be specific challenges for engineering students when adapting to a PBL approach. For example, Nasr and Ramadan (2008) list a variety of challenges they faced when implementing PBL in an Engineering Thermodynamics course. "The majority of students are formulae-driven. Effective methods need to be employed to discourage students from reaching out for quick equations to plug and chug in" (p. 22). Similarly, Johnson (1999) reported that students in a PBL version of a hydraulic engineering course sought "homework problems to improve their understanding of fundamental calculations and help them prepare for exams" (p. 10), despite also expressing concerns that the workload of the PBL course was already burdensome. The students in Johnson's study also complained that the projects were "too vague and needed additional clarification" (p. 11), suggesting a discomfort with ill-structured problems.

Although PBL normally prescribes learning content in the context of new problems, many problems also require the application of prior knowledge. Mitchell and Smith (2008) noted that engineering students had difficulty relating prior knowledge from earlier coursework to the problems provided in a third year PBL course in communications systems. Students spent more time than instructors anticipated trying "to find new information to find a solution to a problem, as if it were just one discrete task, and much less in contemplating how what they were being asked built on previous knowledge and experience" (p. 136). Students also experienced difficulty in the practical nature of the assignments as compared with the more academic assignments they had done in the past. Their written reports showed a tendency toward "replicating rather than applying theory" (p. 138). Students were highly concerned with the grading structure of the course, in particular because they felt that how the various scores were weighted did not appropriately reflect what they had spent the most time on. There were also concerns over group grades versus individual contributions.

Implementation of PBL in the Course MAE 3200 Engineering Materials

Supported by a NSF grant (DUE-0836914), we have designed, developed, and initially implemented a PBL version of MAE 3200, Engineering Materials. The initial implementation of the course for purposes of research was a traditional lecture course enrolling 62 students in the fall of 2009. That version of the course introduced concepts with instructor lectures following the textbook (Callister, 2007). Topics covered are shown in Table 1. The course is taught by two instructors. The course has seven laboratory sessions that reinforce concepts covered in lecture. This version of the course has been taught many times by the professors.

The PBL version of the course, enrolling 58 students, was implemented in the spring, 2010. Students were randomly assigned to ten groups initially consisting of six students each. Students remained in their assigned groups throughout the course. Students then worked in their teams to solve a series of seven problem modules and collaboratively produce a written technical report detailing their group's solution to each. Those problems are briefly described next. Each problem was introduced with a two-page narrative and a set of supports. In order to ensure that important content elements are not missed, the subjects listed in Table 1 that each problem addresses are listed.

Problem 1. *Improved Design of Cassette Plates* – You have been asked to redesign x-ray film cassettes so that they are lighter but retain the same stiffness to bending loads. Compare various materials that are compatible with the application to produce an improved cassette. Addresses: (d, j, k, l).

Problem 2. *Silicon Wafer Orientation* – Write a letter to a confused customer explaining the difference between 100, 111, and 110 silicon wafers and the orientation of the flats on the sides of the wafers. Provide a drawing illustrating the orientation of the crystal in the wafer. Addresses: (a).

(a)	Crystal structures, naming planes and directions
(b)	Imperfections in solids
(c)	Diffusion
(d)	Mechanical properties
(d1)	Tensile Testing
(d2)	Hardness
(e)	Dislocations and strengthening
(e1)	Grain size and strength
(e2)	Solid solution hardening
(e3)	Cold work and annealing
(f)	Failure
(f1)	Fracture
(f2)	Fatigue
(f3)	Creep
(g)	Phase Diagrams
(h)	Phase Transformations
(i)	Heat treatment of alloys
(i1)	Precipitation hardening
(i2)	Quenching and tempering of steels
(i3)	Hardenability of steels
(j)	Ceramics
(k)	Polymers
(l)	Composites

Table 1. Materials related topics to be covered in MAE3200 Engineering Materials course. Topics are listed in the order that they are currently covered in the existing course.

Problem 3. *Variation of Single Crystal Strength* – A bulk single crystal of aluminum is provided to students. Each student cuts a prescribed rectangular cross section sample from any portion of the bulk material, for tensile testing up to failure. However, on testing they find that each student obtains a different value for the elastic modulus and the yield stress. Explain the possible reasons for the apparent discrepancy. Addresses: (d, e).

Problem 4. *Failing Brackets* – In an attempt to improve the strength of mounting brackets, 2024-T3 aluminum is replaced with 7075-T6 aluminum, which is stronger. It is then found that the brackets fail at a higher rate. Determine the reason for this and find another suitable metal alloy that will fix the problem. Addresses: (d1, f1, g, i1).

Problem 5. *Design Improved Automotive Springs* – A hypoeutectoid alloy steel wire containing Cr and V is used for manufacturing coil springs for automobiles suspension systems. These steel springs can be heat treated to obtain excellent toughness and also have high UTS and hardness. This spring wire, purchased from a wire manufacturer, is coiled into springs and heat treated by appropriate quenching and tempering before installation. However, the springs begin to fail prematurely by fatigue failure. What could be the causes for such failures and how could it be remedied? Addresses: (c, d, d1, d2, f, f1, f2, i2).

Problem 6. *Creating Copper Contacts* – Select a beryllium-copper alloy for cell phone battery contacts. They need good conductivity and high strength. If applicable, design a heat treatment for the contacts. Discuss any safety aspects of beryllium. Addresses: (d2, g, i1).

Problem 7. *Design Dies for Forging Ti-6Al-4V Alloy Connecting Rods* – You want to make forged automotive connecting rods from Ti-6Al-4V titanium alloy. Select a tool steel from which to construct the dies and design the proper heat treatment for the dies. Addresses: (d, d2, e, g, i2, i3).

For each problem module, students were provided with a contextualized case scenario introducing them to the details of the problem and their role in solving it; a guide to the module listing the learning objectives; related reading material; and, for the early problems, suggested strategies for approaching the problem. Because students had no prior exposure to PBL, the module guides were used as a form of scaffolding to help them understand both what was expected of them and how to meet those expectations. In the guide to Problem 1 (see Appendix A), instructors provided a detailed task list that modeled how they would approach solving the problem along with conceptual diagrams illustrating the relationships of various material properties to the expected performance of the materials in the implementation. Flowcharts were also provided illustrating the decision-making processes for materials selection and processing. Further, early on in the semester the students were instructed on teamwork and collaboration. In subsequent problems, these supports were gradually reduced so that, by the end of the course, problem scenarios stopped short of describing team problem-solving approaches and problem guides listed only the objectives and requirements for their respective modules.

MAE 3200 is designated as a writing-intensive course in the Mechanical Engineering program, which requires that student assignments take the form of written artifacts similar to the types of writing they might be expected to produce as practicing engineers. Thus, each team was required to produce a written report for each problem module detailing the group's solution to the problem and providing justification for that solution as well as explicating their understanding of the engineering materials concepts related to that problem module. A rubric was used to assess the written reports (see Assessing Your Reports in Appendix A).

Results

The initial implementation of the PBL version of MAE 3200 was exploratory, intended to provide formative evaluation of the methods selected. The primary data source was an indepth interview with 15 of the students following the conclusion of the initial implementation.

Challenges for students. We expected that learners experiencing PBL for the first time would find it challenging, not only because it represents a shift from their prior classroom experiences, but also because much of the benefit from learning how to solve problems within a discipline comes from mistakes made along the path toward mastery. Participants in this study expressed difficulty with the overall structure of the course, and, to a lesser degree, with working in teams.

Participants expressed considerable confusion about the way the course was structured around problems rather than topics. Students perceived the course as effectively lacking structure, describing it as “jumping around on different subjects,” “going backwards,” and “having the test first [before learning the material].” Participants also had difficulty relating their work on the problem modules to the types of questions asked on the course exams.

Student preferences. Students most commonly suggested that more lectures would best address those challenges. Organizing the course around problems rather than topics, however, is a central characteristic of PBL. However, providing supplemental information to help frame particularly challenging topics for students, such as brief, single-topic recorded lectures or other multimedia materials, that students may access on a just-in-time, as-needed basis may help them better appreciate the structure of the course content as it applies to the problem and to the exams.

Working in teams. Most of the students interviewed described their interpersonal experiences with team members as positive and their team roles and structure as informative. Only two of the groups reported particular problems with group dynamics, and the instructors reported that only one student came to them with a request to address interpersonal issues within his group. Given that most participants had little experience working in teams before the course and minimal guidance was provided to students about teamwork strategies, there may be a need for facilitators to be more attentive to group dynamics early in the semester and to provide more direct mentoring to underperforming teams proactively.

Collaboration. Instructors were generally dissatisfied with the quality of the group collaboration as demonstrated by the submitted reports. Instructors perceived that very little collaborative writing. Instead, they observed that students would tend to divide the report into sections and write those sections individually at the last moment, then simply combine those sections with little or no attention to how well the sections fit together. While this improved to some degree over the course of the semester based on feedback from the instructors, students interviewed at the end of the semester expressed that they rarely read their respective teams’ full reports prior to turning them in, though a few mentioned that they used the reports to help them study for exams.

Instructors were also concerned that students were often not making productive use of class time allocated to working together in teams on the problem modules. The PBL model intends for team members to bring their individual research together for discussion so as to teach each other and construct a shared understanding of the meaning of the concepts they are learning (Hmelo-Silver, 2004). While it may not be desirable for the instructors-as-facilitators to police the students during class time, the initial introductory lecture could be enhanced to recommend how to make effective use of class time and facilitators could reinforce these ideas by guiding students back on task when off-task behaviors are observed.

Expectations. Perhaps the most significant difficulty among the students related to the expectations of the course. While the students understood the relevance of the problems, they remained committed most to the exams. The exams were content-based while the problems involved problem-solving activities. In addition to uncertainty over the content on the exams, there was a significant disconnect between the methods that students used to study for the problems and those used to study for the exams. The students studied their textbook for exams and the Internet for information needed for solving the problems. In subsequent implementations, the professors have decided to eliminate traditional exams.

As a result of the uncertainty, the course instructors perceived exam performance to be lower for the PBL students than students who had participated in prior traditional, lecture-based versions of the course. Given that participants themselves identified a lack of understanding how the exams related to their work on the problem modules, however, refinement of the exams is warranted as noted above. Most students had little idea of how much they learned from problems: Their conception of learning is so dominated by traditional expectation guided by traditional examinations.

Instructor challenges. Students face many challenges when making the transition from lecture-based courses to PBL, but the transition is also challenging for instructors. There were two main areas of difficulty for instructors transforming their traditional lecture-based courses to PBL: the transition to the role of facilitator and assessment workload.

In the first implementation, the two instructors alone served as facilitators for all ten groups. They were not provided with significant training in how to facilitate PBL groups prior to the implementation, though as primary members of the research and design teams, they were introduced to the concept of facilitation in this context. Instructors were, as previously mentioned, not readily able to identify issues in group dynamics, primarily because they were spread too thin trying to facilitate all ten groups.

The two instructors performed all of the grading work associated with the course. In the traditional version of the course, students were responsible for individually submitting three written reports as well as taking the two exams. While there were fewer reports at each submission for the PBL students because they were submitted by team rather than individually. The increased workload made it difficult to return student reports in a timely fashion, which in turn affected students' ability to adjust their strategies and improve their performance on subsequent problems.

Since timely feedback is important to promote continued improvement in student performance, some way to alleviate the workload is perhaps the most critical concern for subsequent implementations. It is possible that the additional facilitators could be trained to give general feedback on report structure and cohesiveness, but they will not be qualified to fully assess the student reports.

Conclusion

Implementing PBL in engineering classes represents a challenging transition for both instructors and students. Implementation of any curricular change is a diffusion and adoption of change problem. In this initial implementation, students were challenged to develop new approaches to learning that had different expectations that defied their well-developed study strategies. PBL can be implemented in a variety of ways, from individual course modules to entire curricula. The most successful implementations have been curricular, where all learning in the program of study is problem-based. In those studies, especially those in post-graduate medical programs, content learning between PBL and traditional groups is statistically equivalent, while problem solving skills are significantly enhanced. Course-based implementations are likely to be less successful because the learning and study requirements of PBL courses are so different from traditional courses. We may conclude at the end of the grant cycle that this impediment may be insurmountable.

Next Steps

During the 2010-2011 academic year, we have been collecting research data to assess the effectiveness of PBL vs. traditional, content-based versions of 3200. We are collecting multiple data sources to assess content comprehension, problem-solving skills, and self-regulation skills among the students enrolled in each section of the course. Based on the experiences in the first PBL implementation, we have added scaffolds to help learners comprehend and solve the problem. Each group is responsible for populating a wiki for each problem. Their responses are guided by a series of questions. For the first problem which focused on corrosion, some of the questions included:

- Why would corrosion a problem for outdoor metal structures?
- What evidence (statistics or other proofs) can you cite that supports your answer?
- Can you find another example of a sculpture where corrosions was a problem? What is the source of your information?
- How do you measure and report corrosion?
- Why is it different for metals, ceramics, and polymers?
- Can you predict when corrosion will be a problem?
- What evidence from the case would lead you to conclude corrosion is or is not a potential problem?
- How will aluminum affect the underlying steel structure?
- What is the equation for describing that relationship?

Student response has been positive, and students' efforts have been much more concerted. We will convey initial results of this research at the conference in Vancouver.

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APPENDIX A

1. The Problem to Solve

Directions: Read the Problem. Note the important information in the problem statement.

Groby Industries designs and manufactures x-ray equipment for hospitals and laboratories. Lately, management has become dissatisfied with its market share for the x-ray cassettes used by its hospital customers. Groby has recently been undercut in the market because its closest rival has found a way to produce the cassettes more cheaply. Rather than simply cutting production costs to compete on price, management prefers to improve Groby's existing x-ray cassette design. X-ray cassette

The VP of the design department at Groby has tapped senior design engineer Alex Sparks to manage the project. Alex is meeting with four other engineers in the design department to discuss how to approach the problem.

"Okay, guys," Alex begins, "the marketing department did a customer survey and found out that their biggest complaint about our x-ray cassettes is that they are too heavy. The x-ray technicians at the hospitals handle a lot of cassettes during their shifts. They said that, in addition to positioning patients, transporting the x-ray cassettes is the most physically demanding part of the job. Our VP says that the best way to increase our sales would be to make the cassettes lighter."

Jocelyn replies, "Okay, since I'm new to Groby, I just want to check my understanding here. The cassettes hold the film while the x-ray is being taken, right?"

"That's right, Jocelyn," Alex replies. "It's very important that any solution we propose will still hold the film rigidly in place during patient exposure. It also can't allow any light to get to the film."

"If the cassette is light-tight, how does the film get exposed?" Jocelyn wonders aloud.

"On the inside of each cassette, there is a scintillating material that produces light when exposed to x-rays," Alex explains. "This is how the film gets properly exposed by the x-ray machine."

Charlie, another member of the team, has worked extensively on the design of Groby's biggest selling x-ray machine, though he was not directly involved with designing the current cassettes used in it. "Let's not forget," he interjects, "the re-designed cassettes still have to work with the machine itself. They must have the same width of 500 mm and height of 400 mm or they won't fit right in the machine."

"Well, if we just want to make the cassettes lighter," suggests Zac, "couldn't we just make the face plates thinner? They're pretty dense, right?"

"The plates are currently 0.5 mm thick," replies Sunil, who was the lead designer for the current cassettes.

Charlie adds, "As long as the width and height of the cassette remains the same, there should be no problem with making them thicker or thinner within reason, at least in terms of how they will fit in the machine."

"Sure, Charlie," Sunil continues, "but we won't be able to move in a direction that requires increasing a patient's exposure to get the same exposure on the film. We also have to keep the rigidity of the current plates."

"How would a patient get a higher exposure, Sunil?" asked Charlie.

"If the new plates absorb x-rays more than the current design, the patient will have to receive a higher exposure to get the same amount of exposure on the film."

"Does that mean we can reduce the patient exposure if we select a material that absorbs less than the current design?"asked Jocelyn.

"Yes, it does," replied Sunil, "but the current design is transparent enough to x-rays that it probably won't make much difference. The lawyers would never let us move in the other direction though."

"@!#$%$^@^ laywers!" they all mumbled under their breath in unison.

Jocelyn asks, "What material are we using to make the plates now?"

Sunil replies, "an aluminum alloy."

"Sunil and Charlie raise some good points," Alex says. "Let's also remember that our new plate design is required to have similar or lower deflections and a reasonable amount of toughness and strength."

"So how do we get started, Alex?" Zac inquires.

"I think we need to look at different materials as well as the possibility of just making the current plates thinner," Alex replies.

"I can use our database to find alternative materials that might work," says Jocelyn, "but that's not going to tell me what impact they might have on patient exposure to x-rays."

"Since I worked on the original cassette design, I have some reference materials about x-ray dose we can use," Sunil tells Jocelyn. "Alex, I can be responsible for evaluating potential designs for dose considerations.I'll set up a spreadsheet for the calculations for different materials and when you finalize potential thicknesses, I can calculate the absorption."

"Great," says Alex. "What else?"

"I'll work on the numbers for the different materials, including the current aluminum alloy, at different thicknesses so we can compare them," Zac replies.

"I can be the quality control engineer," says Charlie, "and review the designs to make sure they will work right with the x-ray machine."

"This sounds good. I will make a project plan for our team to complete the work. Management wants a proposal for the redesign by Monday. I need you to let me know right away if you are going to have trouble meeting your deadlines for your tasks. Let's meet the day after tomorrow and talk about what we've found."

"So you'll write the proposal, Alex?" asks Jocelyn.

"I'll prepare the final version," Alex responds, "but we all need to contribute to the proposal. We will need to explain our material choice, along with other design considerations such as the thickness we'll propose, and demonstrate that our new design will result in a lighter cassette that works with the existing equipment and produces no greater exposure to patients. Everyone has a piece of that information, so we'll need to work as a team to put it all together."

2. How to Approach this Problem

Directions: Analyze the problem by completing each of these tasks.

1. A. Determine performance problem (e.g., cassettes too heavy, cause injury)

B. Determine performance goal (e.g., modify cassette to be lighter, non-toxic, with same functionality)
C. Determine performance characteristics (e.g., lighter, stronger , faster, bending stiffness, x-ray transmission) for job
D. Identify solution options (e.g., substitute material with lower density, use less material)
2. For each performance characteristic, determine the material properties that affect that performance
a. Repeat until done:
i. Identify primary material properties (elastic modulus, density, x-ray attenuation) that affect/control each requirement
ii. Identify secondary material properties (e.g., fracture toughness, compatibility with people, poison danger) that affect/control each requirement
iii. Identify and map the factors that affect that property and the factors that will be affected by that property and how they are affected (see Figure 1)
iv. Which properties require a limiting value for the application? (e.g. fracture toughness must be at least 10 $\text{MPa}\sqrt{\text{m}}$)
vi. Which properties should be optimized (maximized, minimized)? (e.g. minimizing the density can minimize the weight, all else being equal)
vii. Rank properties in terms of importance
viii. Determine interactions among requirements (e.g. density and elastic modulus cannot be varied independently with materials. Increasing thickness to increase stiffness increases the weight. You can find that the maximum $E^{1/3}/r$ minimizes weight)
b. Determine final ranked property list
3. Explain microstructural origin of required material properties: How are material properties achieved in the material? The paradigm illustrated in Figure 2 will help in considering the origin of the properties.
4. a. Identify class of materials that should meet those properties
b. Select 5-10 candidate materials from a database or other sources
5. Select equation(s) and calculate changes to material performance for each alternative
6. Does material need to be processed to achieve the desired properties?
6a. If yes, develop material processing necessary to meet the desired/required material properties.
7. Examine candidate materials in greater detail
8. Determine pros and cons for candidate materials
9. Develop argument in favor of final choice
10. Develop counter arguments against materials not chosen
11. Iterate between 9 and 10, change choice if necessary.

3. Assessing Your Reports

For each criterion, we will assign the statement and value that best describes the quality of your report. The first submission and final submission of a report will each count for 50% of the final score for that assignment.

Determination of performance problem ______

3 All performance characteristics of problem (e.g., weight, speed, structural strength, thickness, stiffness, higher or lower temperature) identified; all characteristics relevant to problem
2 Most performance characteristics identified; all relevant to problem
1 Only a few performance characteristics identified; some not relevant to problem
0 No performance characteristics identified

Required performance characteristics ______

4 All performance characteristics stated using appropriate descriptors (e.g., lighter, stronger, faster, bending stiffness, x-ray transmission)
3 Most performance characteristics stated, all with appropriate descriptors
2 Most performance characteristics stated, some with appropriate descriptors
Few performance descriptors stated
0 No performance descriptors stated

Range of performance characteristics ______

2 Range of performance characteristics appropriate (too many characteristics or too few characteristics described
1 Range of performance characteristics inaccurate

Ranking of performance characteristics ______

3 Ranking of performance characteristics to be maximized or minimized by material selection are appropriate to task.
2 All performance characteristics stated but improperly ranked
1 Performance characteristics and ranking inappropriate

Material properties (for each performance characteristic) ______

3 All primary and secondary material properties identified for each performance characteristic
2 Most primary and secondary material properties identified for each performance characteristic
1 Some primary and secondary material properties identified for each performance characteristic
0 No primary and secondary material properties identified for each performance characteristic

Physical factors and their effect on material properties _______

3 All physical factors and their effect on material properties stated
2 Most physical factors and their effect on material properties stated
1 Some physical factors and their effect on material properties stated
0 No physical factors and their effect on material properties stated

Ranking of material properties ______

2 Ranking of material properties in order of importance
1 All materials properties ranked; some out of order out of order
0 No ranking of material properties

***Identifying Interactions among material properties on performance* ______**

3 All interactions among material properties on performance stated correctly (e.g. 2 increasing the thickness will increase the stiffness but may increase the weight)
2 Most interactions among material properties on performance stated correctly
1 Some interactions among material properties on performance stated correctly
0 No interactions among material properties on performance stated correctly

***Quantifying interactions* ______**

3 All interactions among material properties and performance correctly quantified using appropriate equations
2 All interactions among material properties stated but equations are not all accurate
1 Some interactions among material properties and *performance* correctly quantified using appropriate equations
0 No interactions among material properties correctly quantified using appropriate equations

***Calculation of changes* ______**

3 Correct calculation of changes from a baseline
2 Partially correct calculation of changes from a baseline
1 Inaccurate calculation of changes from a baseline
0 No calculation of changes from a baseline

***Advantages of chosen material* _______**

2 All important advantages of material stated to justify selection
1 Some important advantages of material stated to justify selection
0 No important advantages of material stated to justify selection

***Rebuttal arguments* ______**

3 Rebuttals to alternative materials provided listing appropriate material properties and interactions
2 Rebuttals to alternative materials provided but missing some material properties and interactions
1 Rebuttals to alternative materials provided with inappropriate justification
0 No rebuttals provided

***Science Section* ______**

4 Relevant materials science principles identified and correctly explained
3 Most material science principles identified and correctly explained
2 Significant materials science principles omitted or inaccurately explained
1 Science section completely misses relevant issues in the problem
0 Science section omitted

***Report Writing* ______**

4 Completely and consistently follow MAE 3200 Report Writing Requirements
3 Usually follows MAE 3200 Report Writing Requirements with some exceptions
2 Inconsistently follows MAE 3200 Report Writing Requirements
1 Very rarely follows MAE 3200 Report Writing Requirements