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Open-book problem-solving in engineering: An exploratory study

Abstract

The bulk of educational research exploring open-book examination demonstrates that the open-book format reduces student anxiety and promotes higher-level learning (i.e., reduces reliance upon rote memorization and prompts students to focus on understanding concepts and principles). Previous studies examining open-book assessment provide evidence that students exhibit better performance on open-book exams compared to closed-book exams. In addition, many university faculty find it advantageous to employ exams using an open-book format, especially in engineering. However, within engineering we know little about how students approach open-book testing, particularly with regard to how they spend their time on different tasks and how this division of time may affect performance.

The study in this paper examined the testing behavior of 8 senior materials science and engineering students at a large public university in the southeastern US. Students completed four engineering problems during individual laboratory sessions while engaged in a think-aloud procedure (i.e., verbally explaining their thought processes as they worked through the problems). The problems were designed to vary in terms of their closed or open-endedness and the number of decision points involved in their solution. Students’ think-aloud protocols were categorized to determine the amount of time spent on each of five exam behaviors: reading from the textbook, writing, calculating, reading the test question, and talking/reflecting. Problem solutions were separately graded using a previously created rubric. The time spent on various behavior categories were then examined with respect to grades students received for their solutions. Reading from the textbook represented the bulk of students’ time on the problems (35% on average). Interestingly, there was a significant negative correlation between time spent reading the textbook and students’ grades. The more time that students spent with the text, the more poorly they performed. This correlation was strongest for students who had the lowest solution scores, but was still evident for students with the highest scores. Students with the lowest scores tended to search the text for information or an example problem to guide their approach to the problem, while students with the highest scores tended to use the text to confirm their knowledge. This data suggests that for our sample the textbook may have served as a distraction. The results highlight the importance of training students in the effective use of resources during open-book exams so as to avoid distractive behaviors. This training would serve not only to improve exam performance, but to educate students in the effective use of resources for professional practice where open-book problem-solving is the norm.
Introduction

A critical educational goal for any engineering program is the preparation of students for the workplace. An important set of learning tools employed during this process are textbooks. Students are often first introduced to engineering concepts through their interaction with text materials. Practicing engineers are also dependent upon textbooks (or other reference materials) to successfully conduct their work (e.g., assessing materials properties or relative costs). It is clear that engineering textbooks are appropriate for learning about algorithms and formulae and later, in the field, they are frequently consulted. However, our review of the engineering literature reveals little understanding of how students make use of texts and reference materials (Bhaskar & Simon, 1977; Jonassen, Strobel, & Lee, 2006). The purpose of the present descriptive and correlational study is to begin to document that behavior by explicitly examining students’ use of text materials when problem solving.

Problem solving, whether by students or professionals in the field, often requires multiple skill sets. With this mind, consider the two following engineering problems:

(1) A cylindrical rod of single crystal nickel with a radius of 2 cm yields when a tensile force of 17.47 kN is applied along its length. This force is being applied in the [001] direction. Slip occurs on the (111) plane in the [01] direction. What is the critical resolved shear stress for this slip system?

(2) A truss bridge requires 40 members of square cross-section each of which is 12 feet long and experiences its maximum load in tension. The bridge is designed so that the maximum load experienced by each member is 500,000 lbs. You are bidding on the contract to provide these 40 members. The weight of each member cannot exceed 350 lbs as this is the lifting limit of the crane that will be used to construct the bridge. Provide a recommendation as to the specifications for these members and the cost for the job.

The first problem is perhaps easily identified as drawn from an introductory textbook. It is well specified and the solution is bounded. This is contrasted by the limited constraints of the second problem which has a number of possible solutions. The second question is further complicated by the addition of conflicting goals such as balancing costs and durability, or cost and aesthetics. Engineers are faced with questions of this second kind or what have been termed “workplace problems” and are hired and retained based upon their skill to handle the open-endedness of such questions (Jonassen, Strobel, & Lee, 2006). To our knowledge, neither of these problem types has been explored with respect to the student-text interaction. Consequently, our study explores how students use relevant text materials for both traditional problems found in educational settings (i.e., close-ended, bounded, example type problems) and workplace problems (i.e., open-ended, ill-structured).

It is important to explore the student-text interaction further because university faculty are increasingly making use of open-book exams, especially in engineering, where the sheer volume of formulae and tables needed to solve problems make memorization a difficult proposition (Gray, 1994). The increasing use of the open-book format in engineering education also underscores the importance of exploring this phenomenon within the discipline. In the balance of this paper, we examine research from educational psychology documenting the benefits and pitfalls of open-book testing. Using this literature as a base, we conducted an...
exploratory study assessing how engineers approach open-book problem solving (i.e., what tasks they spend their time on and how this division of time may affect performance).

On the merits and controversies of open-book testing

A substantial amount of research in the field of education has charged itself with identifying and developing exams that align with instructors’ course goals and accurately assess students’ understanding. Traditional exams (i.e., closed-book exams) successfully measure students’ ability to memorize important facts, identify students who are conscientiously keeping up with their reading assignments, and provide instructors with a superficial insight into the level of understanding students have in their course (Tussing, 1951). However, a common limitation of closed-book exams is that they provide an incomplete assessment of students’ actual understanding (Kalish, 1958; Tussing, 1951) and have a tendency to promote surface level approaches to learning. In contrast to instructivist approaches that typically employ closed-book exams, educational practices are moving towards adopting constructivist approaches to teaching and assessment. Constructivists emphasize deep learning through active engagement, encouraging students to build off of their existing knowledge (Williams, 2006). Research on the use of open book exams is an area of growing interest in the pursuit of this goal.

The main criticism against the sole use of closed-book exams is that such exams place too much emphasis on rote memorization of facts (Feller, 1994; Tussing, 1951) which may have detrimental effects on teaching practices as well as students’ learning outcomes. When closed-book exams are the only form of assessment in a course, there is a greater likelihood that an instructor’s teaching practices are driven by the questions on the exam (Feller, 1994). In addition, closed-book exams typically consist of true and false or multiple choice questions that measure students’ ability to rehearse and recite large amounts of facts from a textbook and/or an instructor’s lecture notes (Feller, 1994; Tussing, 1951). Closed-book exams tend to foster surface approaches to learning in which students simply reproduce what they are given and accept it without question (Baillie and Toohey, 1997). Students have a tendency to take the “cram-unload-and-forget” (Tussing, 1951, p. 598) approach when studying for closed-book exams. In this way, closed-book exams can undermine the development of higher order skills such as the application, synthesis, and evaluation of information that most instructors agree encompass their overall course goals (Tussing, 1951).

Another argument against closed-book exams is that they have little or no applicability to the real world. Once students enter the workforce, the problems they encounter will not be constrained to a single correct solution nor will they be left without access to reference materials if needed (Boud, 1991; Feller, 1994; Gibbs, Habeshaw, Habeshaw, 1988; Williams, 2006). Finally, critics of closed-book exams argue that students are more susceptible to unnecessary exam anxiety and stress due to the arduous memory task involved and fear of not being able to correctly recall specific facts (Theophilides & Dionysiou, 1996; Tussing, 1951).

An alternative approach to assessment that has gained considerable attention is the open-book exam. The format of open-book exams differs from closed-book exams in that they consist of comprehensive questions which do not focus on recall of facts but instead, on the application of knowledge to real world problems (Feller, 1994). Questions on open-book exams are designed to prompt synthesis of information from various sources, appropriate application of information, and an evaluation and justification of the solution reached (Baillie & Toohey, 1997). Therefore,
the nature of open-book exams replaces surface level approaches to learning common with closed-book exams, and instead encourages students to engage higher order cognitive skills (Baillie & Toohey, 1997; Theophilides & Dionysiou, 1996) as well as placing the emphasis on improving understanding instead of memorization of facts during the learning process (Eilertsen & Valdermo, 2000).

The deep approaches to learning that open-book exams aim to promote involve behaviors such as consulting and relating various sources of information, identifying gaps in knowledge, and evaluating outcomes of one’s learning (Eilertsen & Valdermo, 2000). Gray (1994) found that mechanical engineering students made more annotations and insertions in their notes while studying for open-book exams, indicating a deeper study of course material. In addition, students were more likely to raise apparent inconsistencies between course notes and text (Gray, 1994) providing evidence that students were critically evaluating the information they were being presented. Another study investigating materials engineering students employed an open-book exam called a “Power Test” that allowed students to solve challenging problems without any time constraints. In addition, students were also given the opportunity to confer with colleagues during the exam, mimicking the conditions of a real workplace (Baillie & Toohey, 1997). The open-book exam was believed to match course goals (e.g., developing the ability to consider various structures and properties of materials in order to identify necessary criteria) when making a materials selection for a problem (Baillie & Toohey, 1997). Results showed that students’ answers on open-book exams were of much higher quality compared to answers the same group of students had produced on a closed-book exam (Baillie & Toohey, 1997). Agarwal et al. (2008) also provide evidence that open-book exams lead to better student performance when compared to a closed-book control. These findings suggest that preparing for open-book exams aids students in developing knowledge and skills that translate to real world application. In addition, the process of taking an open-book exam simulates the way engineers in the workplace approach problems, including the ability to quickly retrieve relevant sources of information and appropriately use references (Baillie & Toohey, 1997; Gibbs et al., 1988). Students who take open-book exams also report a reduction in anxiety and stress that is commonly associated with closed-book exams (Feldhusen, 1961; Jehu et al., 1970; Theophilides & Dionyiou, 1996).

Overall, studies support the merits of open-book exams, and there is growing support for using this approach in assessing students. Open-book exams have been shown to promote deeper, more meaningful approaches to learning, have greater real world application value, and reduce exam stress. However, other studies taking a deeper look into open-book exams have found mixed and even contradictory findings on its perceived benefits.

One apparent drawback to employing open-book exams is that students’ may hold misperceptions about the relative ease of this form of assessment. Students are less likely to prepare if they have a false sense of security in open-book exams (Baillie & Toohey, 1997; Feller, 1994; Gray, 1994; Ionannidou, 1997; Theophilides & Dionysiou, 1996). Other issues include students consulting too many references and ineffectively using their time by flipping through various sources in search of an answer (Gray, 1994). Reading large passages from a textbook during an exam is a time consuming process and may also hinder performance, especially for students who are expecting to find answers to exam problems. Textbooks also tend to be less focused than course curricula and therefore less applicable to exams (Gray, 1994).
Carrier (2003) found that strategies such as taking notes from textbooks and highlighting were negatively correlated with student scores on an open-book exam. Carrier (2003) suggests that “hunting down and looking up information in the textbook and lecture notes” (Carrier, 2003, p. 55) impedes student ability to successfully solve exam problems, especially when time constraints are present. Ineffective use of references coupled with a lack of preparation both appear to contribute to poorer performance on open-book exams.

Another finding that contributes to the growing controversy over open-book exams is students’ reports of increased anxiety due to the unfamiliar format as well as time constraints (Baillie & Toohey, 1997; Eilertsen & Valdermo, 2000; Gray, 1994; Ramsden, 1992). Exam stress, considered to be a major drawback of closed-book exams, may also exist in open-book exams, but for different reasons. Some studies have also failed to show a difference in performance between closed and open-book exams (Ioannidou, 1997; Jehu et al., 1970; Kalish, 1958). There is evidence that open-book exams may not measure different abilities than closed-book exams when both types of exams are designed to test critical thinking and higher order skills (Ioannidou, 1997). Krarup, Naerra, and Olsen (1974) provided evidence that student performance was greater on an open-book exam compared to a closed-book exam, but only on items that required simple recall; this difference was not found on items at higher taxonomic levels.

Further research is needed to expand our understanding of open-book testing in engineering. A first step could be to identify student behaviors that differentiate performance. The present study aims to provide some insight in this direction by documenting various approaches exhibited by a group of senior undergraduate materials engineering students on an open-book problem solving activity and equating these behaviors with performance. Specifically, this study investigates the relationship between time spent on different problem solving activities and students’ scores, as well as analyzing transcribed think aloud sessions to identify different conceptual approaches to textbook use.

Methods

Participants

Eight undergraduate seniors majoring in materials engineering at a large public university in the southeastern United States participated in the study. All seniors in the major (there were a total of 40 in the program) were invited to participate and the first eight to sign up were selected for the think-aloud study. Think-aloud methodology employs an intensive data collection process; providing a dense, rich, and valid data set with typically smaller sample sizes. Nielson (1994) argues that think-aloud designs with 5 or more participants are sufficient to gather information about problem solving. Our data was gleaned from 8 participants (16 total hours of problem-solving behavior). Participants received a gift card to a big box retailer as compensation. Senior students were selected because they have received the bulk of their training and are soon entering the engineering field. Participants were all native English speakers and each took approximately two hours to complete the problem-solving session. The study was approved by the Institutional Review Board at the University of Florida and all participants signed an informed consent form.

Materials
Four materials engineering questions were developed for this study representing a range of closed- and open-endedness as well as various levels of complexity. Before use in this study, the problems were evaluated by a panel of engineering faculty (n = 4) to insure internal validity. These four problems can be found in Appendix A. Students who participated in the study were also provided with paper on which to work out their solutions, writing instruments, a calculator, and a copy of a materials engineering textbook (Callister, 2007) to use while solving the problems. All of the participants were familiar with the supplied textbook as it had been required in an introductory class taken by all of the participants.

Procedure

Participants were instructed to report their thoughts aloud while solving each of the four problems. This is a common procedure used in cognitive psychology referred to as a “think aloud” or “verbal protocol task” (Ericsson & Simon, 1993; Pressley & Afflerbach, 1995). Verbal protocols provide a window into participants’ cognitive processes as long as the reports remain subordinate to and concurrent with the primary task (i.e., solving the problems). Verbal protocols have been used extensively in problem solving research. The experimenters modeled the think-aloud procedure with a practice task (e.g., write as many different cities as you can for 2 minutes while reporting how you are going about the task). Participants were then asked to practice using animal types. As described by Ericsson and Simon (1993), only one practice session is typically needed because thinking aloud is a natural process that does not require extensive training. Participants were only allowed to work on one of the four problems at a time, and the order in which the problems were presented to each participant was randomized. Participants were allocated 30 minutes to complete each problem, although this limit was not strictly enforced (i.e., it was used as a guideline, participants who ran over the 30 minutes were prompted to try and provide the best answer possible and given a few more minutes). The 30 minute completion time was incorporated to ensure that students wouldn’t spend the entire time on a single problem. A researcher was present throughout each problem solving session to prompt participants if they stopped verbalizing for more than 30 seconds.

A grading rubric was developed for each of the problems and was weighted by the number of critical decision points in each problem to ensure that the problems could be directly compared. The rubric was then used to score the students’ solutions based on the percentage of critical decisions the participant answered correctly on a scale of 0-100%. The researcher who graded the problems did not know the identities of the participants. After all of the participants’ solutions had been graded, the video data of the participants’ think aloud sessions were reviewed.

Video data were categorized into 6 distinct activities: reading the textbook, using a calculator, writing (assumably working on the problem), talking or reflecting on the problem (as instructed by the think-aloud directions), or reading/re-reading the problem statement. These categories were generated by the researchers a priori, but were revised slightly after categorization. Namely, a single category (that of “checking one’s work”) was removed from the original list because students engaged in that activity infrequently (less than 1% of their total time). The researcher who categorized the video data was not the same person who graded the solutions, in order to avoid any bias in either analysis activity.

Descriptive Analyses and Results
Analyses of the problem solving activity from the 8 participants revealed that they allocated 31% of their time to talking and reflecting upon the problem. This is not surprising, indicating that participants were following the directions to verbally report their thoughts throughout the problem solving session. Participants spent 21% of their time working on the problem through writing, 8% of their time reading the problem statement, and 4% using a calculator. Most surprising was the fact that students spent the largest proportion of their time (35%) either reading or searching through the textbook.

The time allocation data was further examined as a function of solution scores. There was a significant negative correlation between time allocated to the textbook and solution grades ($r = -.6, p < .01$). Increased time spent engaged with the textbook was associated with lower grades. No other activity significantly predicted performance on the problems. To assess the possibility that individual skill could be driving this finding (i.e., that those who scored lowest had less domain knowledge and thus had more to learn to complete the problems) we conducted a median split on participants’ performance solving the problems (see Table 1). The high-performing group had an overall average score of 71% compared to the low-performing group with 54%.
Table 1. Problem activity breakdown (in minutes) and accuracy scores (%) for high performing and low performing students (median split, n = 8).

<table>
<thead>
<tr>
<th>Activity in Minutes</th>
<th>Text</th>
<th>Calc</th>
<th>Writing</th>
<th>Talking</th>
<th>Quest</th>
<th>Avg Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Performing Participants</td>
<td>Closed-Few (Crystal)</td>
<td>3.17</td>
<td>0.67</td>
<td>2.78</td>
<td>2.59</td>
<td>1.11</td>
</tr>
<tr>
<td></td>
<td>Closed-Many (Corrosion)</td>
<td>8.50</td>
<td>0.49</td>
<td>3.23</td>
<td>4.35</td>
<td>1.74</td>
</tr>
<tr>
<td></td>
<td>Open-Few (Platform)</td>
<td>5.67</td>
<td>1.42</td>
<td>4.44</td>
<td>8.33</td>
<td>1.82</td>
</tr>
<tr>
<td></td>
<td>Open-Many (Bridge)</td>
<td>4.85</td>
<td>1.06</td>
<td>5.76</td>
<td>4.97</td>
<td>2.23</td>
</tr>
<tr>
<td>Overall Average</td>
<td>5.55</td>
<td>0.91</td>
<td>4.05</td>
<td>5.06</td>
<td>1.73</td>
<td>71.69</td>
</tr>
<tr>
<td>Low Performing Participants</td>
<td>Closed-Few (Crystal)</td>
<td>6.94</td>
<td>0.98</td>
<td>4.38</td>
<td>5.14</td>
<td>1.02</td>
</tr>
<tr>
<td></td>
<td>Closed-Many (Corrosion)</td>
<td>15.86</td>
<td>0.61</td>
<td>4.09</td>
<td>7.49</td>
<td>2.28</td>
</tr>
<tr>
<td></td>
<td>Open-Few (Platform)</td>
<td>3.59</td>
<td>0.70</td>
<td>4.13</td>
<td>5.58</td>
<td>1.19</td>
</tr>
<tr>
<td></td>
<td>Open-Many (Bridge)</td>
<td>5.85</td>
<td>0.32</td>
<td>4.28</td>
<td>10.23</td>
<td>1.83</td>
</tr>
<tr>
<td>Overall Average</td>
<td>8.06</td>
<td>0.65</td>
<td>4.22</td>
<td>7.11</td>
<td>1.58</td>
<td>53.56</td>
</tr>
</tbody>
</table>

The data in Table 1 suggest that students allocated their time similarly across activities, with only minor exceptions. For example, low-performing participants spent additional time reading the text, but this difference was not significant. It should be noted that our sample size was considerably smaller with the median split, thus contributing to a loss of power. Consequently, we are hesitant to comment on specific time differences between problem types. Overall, our data provide evidence of a significant negative correlation between time allocated to reading the textbook and grades obtained for the low-performing students ($r = -.68, p < .01$). In the case of the high-performing students, the data also suggest a negative trend ($r = -.45, p = .08$).

Representative Samples of Students’ verbalizations

To further explore how students interacted with the textbook, transcript passages associated with textbook use were examined. The following samples provide examples of
students’ verbalized thoughts, illustrating the variety of approaches observed in using the textbook during the problem solving activity.

Many of the low-performing participants used the textbook to locate an example problem. Students articulated: “[I don’t have a clear time so before ... Just reading the example” or “[I thought it would be something so easy, to just (looking through book)... If I just see one problem then I can go from there.” Alternatively, students decided to use textbook equations instead of other alternatives (i.e., equations that they remembered or were familiar with) as illustrated in the following example. “I’m just reading the thing they say about slip in a single crystal along with what appears to be the equation, so I’m just going to use their equation instead.”

Some students’ intentions were more specific. For example, one student stated that he uses practice problems to prompt memory “I think I can dot product the two of them to figure out what that is. If I remember right, I haven’t done these problems in a few years. For a year. So I’m just going to look at the practice problem to remember” Another student used examples to find something comparable to the stated problem “Just looking at if they have an example maybe comparative to look at”. It was also clear that students relied on visual aids such as pictures to help them conceptualize the problems. However, it was not always clear to the students whether the example problem was going to be helpful. For instance, one student noted: “This is ... I like looking at example problems because they usually are good ideas, but some of these don’t come close at all so won’t help me.” Finally, some low-performing students used the textbook without specific direction; one student described: “Let’s see if there’s anything helpful in the book. Thought that there were tables relating some of these. Hmm. Um, let’s see” another stated “Um, look in the book and see if I can find any kind of guidance”

In comparison to the low-performing participants, examples from high-performing participants often illustrated purposeful uses of the textbook. These students had a plan regarding what to search for and how to access the book effectively. For example, one student commented: “So, I know what I’m looking for here as soon as I can find the chapters because ... I’ll just go to the back. It’ll be easier to look in the index for the critical resolved shear stress which is what I’m trying to solve for. It tells me exactly what page it’s on because I don’t remember the formula off the top of my head or how to find the angles”. Many of the high-performing students also used the textbook for verification purposes (i.e., to make sure that their equations were appropriate and suitable for the particular problem) as illustrated in the two following examples: And they’re asking, “What is the critical resolved shear? So I think I know what that equation is but I’ll look it up just to make sure. (Looking in book) Oh, right here. Page 205, that was convenient.” and “No, the applied stress and the slip direction. So I know how to figure out those two. I’m just going to check.” (Flipping pages) “Right.”

Discussion and Conclusions

Educational research exploring open-book problem solving demonstrates that this format reduces anxiety and promotes deeper learning (i.e., deemphasizes rote memorization). Further, some studies provide evidence of gains of roughly a full letter grade on open-book exams when compared to a closed-book control (Agarwal, et al.; 2008). Open-book problem solving also appears to better simulate engineering practice than closed-book testing (Jonassen, Strobel, & Lee; 2006).
Despite the obvious advantages of using open-book exams as suggested by the literature, the results from our study strike a cautionary note. Our results mirror Grey (1994) and Carrier’s (2003) findings that student performance can be hindered by an overreliance upon the textbook (e.g., reading large portions of the text verbatim during an exam or hunting through the book for a perfect example problem) and that this may lead to ineffective time management. Our results indicate that reading or searching the textbook consumed the largest portion of our participants’ problem solving time and was always negatively associated with their performance. This effect was obtained without the use of strict time limits and was evident irrespective of student ability as measured by overall problem performance in the median split. However, we think it will be fruitful in future work to further examine specific characteristics of our students including domain knowledge and working memory and to include a control condition (e.g., where students attempt the same problems without a text, or are provided with a simple listing of relevant formulae). In addition, a qualitative analysis of students’ verbalizations for the textbook category will provide greater insight on the different strategies used during open book problem solving. For example, a think aloud analysis of students solving various types of physics problems revealed notable differences in the way successful versus less successful students employed example problems during the problem solving phase (Chi et al., 1981). Inclusion of these elements will help us to move beyond the descriptive nature of the current work and begin to formulate clearer causal links between students’ scores and the use of the textbook.

This study provides a first look into how engineering students approach open-book problem solving and is part of a multi-year research effort examining how students solve engineering problems. Our results highlight the importance of training students in effective means of using resources during open-book exams so as to avoid distractive behaviors. This training would serve not only to improve exam performance, but to educate students in effective use of resources for professional practice where open-book problem solving is the norm.

Acknowledgement

We wish to thank the National Science Foundation for funding the current work through grant # 0909976.

References


Appendix A

Closed-ended Few Decisions Problem (Crystal)

A cylindrical rod of single crystal nickel with a radius of 2 cm yields when a tensile force of 17.47 kN is applied along its length. This force is being applied in the [001] direction. Slip occurs on the (111) plane in the [ 01] direction. What is the critical resolved shear stress for this slip system?

Closed-ended Many Decisions Problem (Corrosion)

An iron bar with the dimensions as shown below is being used as a structural support member underwater in the presence of HCl. Corrosion occurs only on the top surface (marked T in the figure below) and the corrosion current measured on this surface is $1.58 \times 10^{-2}$ amperes. This structural member is inspected periodically using ultrasound, and the smallest internal crack that can cause failure is 6 mm (you may assume there are no surface cracks). The plane strain fracture toughness of the iron is 41 MPa-m$^{1/2}$. The force applied to this member is 1,750 kN in the direction as shown in the figure. How long can this member remain in service before it needs to be replaced?

Open-ended Few Decisions Problem (Platform)

A large tower is to be supported by a series of wires. It is estimated that the load on each wire will be 12,000 N. The design requires a design factor of 2. Select an appropriate material for these wires and the wire diameter. You must show how you arrived at this choice.

Open-ended Many Decisions Problem (Bridge)

A truss bridge requires 40 members of square cross-section each of which is 12 feet long and experiences its maximum load in tension. The bridge is designed so that the maximum load experienced by each member is 500,000 lbs. You are bidding on the contract to provide these 40 members. The weight of each member cannot exceed 350 lbs as this is the lifting limit of the crane that will be used to construct the bridge. Provide a recommendation as to the specifications for these members and the cost for the job.