Enhancing Critical Thinking Skills Through the Incorporation of an Open-Ended and Ill-Defined Project in a Technical Core Course

James P. Solti and James M. Greer, Jr.
Department of Engineering Mechanics
United States Air Force Academy

Introduction

E*ngineering Mechanics 200 (EM 200) - Fundamentals of Mechanics* is an introductory "core" course which all students are required to complete prior to the start of their fifth semester at the U.S. Air Force Academy (USAFA). This course offers an integrated introduction to the Mechanics of Materials and to Statics. The course is not a preparatory course for engineers in which students are asked to learn fundamental engineering principles for a future semester (only about 10% of the cadets taking EM 200 will actually major in engineering). Rather, course objectives are focused on the development of "higher-order cognitive skills" such as problem solving and critical thinking. Additional objectives are aimed at improving the student's ability to visualize and understand the world around them. Figure 1 illustrates the four cornerstones of EM 200.

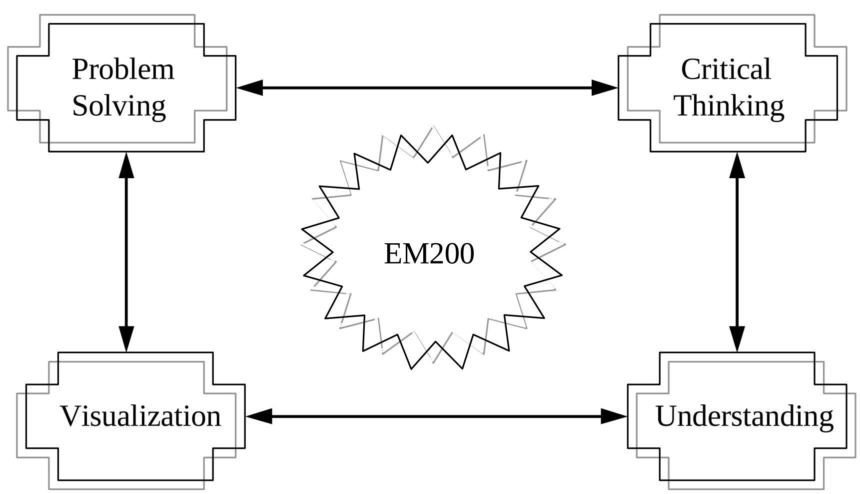

Figure 1. EM 200 and the development of problem solving skills

To facilitate the development of these skills, this semester (Fall 1997) EM 200 has introduced a "real-life ill-defined" problem into the syllabus. The effects of introducing this type of problem into a non-engineering major's class, on both instructors and students, are described.

The EM 200 Class

In recent semesters, EM 200 has had an enrollment of approximately 600 sophomore cadets (some freshmen take the course in their second semester if they have advance placed in mathematics). In order to meet the USAFA student/teacher ratio requirements, these students are divided among 25-30 sections, and taught by a cadre of a dozen instructors having a wide range of teaching experience. The Course Director (CD) has responsibility for course content and oversight during the semester, and holds weekly meetings with the instructors to insure consistency of instruction and to discuss any issues that come up during the course. The course objectives of EM 200 are:

1. Develop an appreciation for the importance of mechanics by all cadets.
2. Develop the capability to apply rudiments of engineering mechanics by all cadets.
3. Improve the ability of all cadets to think critically.
4. Improve the ability of all cadets to communicate (technical information) effectively.
5. Provide the opportunity to frame and resolve Ill-Defined problems (problem solving skills).
6. Provide a forum for the instructors to assess their own pedagogical prowess.
7. Continue to integrate the USAFA educational outcomes into the classroom experience.
8. Facilitate technology integration into the classroom.

The objectives have been specifically formulated to serve the higher institutional objectives, which the USAFA refers to as "educational outcomes."

1. Officers who possess breadth of integrated, fundamental knowledge in the basic sciences, engineering, the humanities, and social sciences, and depth of knowledge in an area of concentration of their choice.
2. Officers who are intellectually curious.
3. Officers who can communicate effectively.
4. Officers who can frame and resolve ill-defined problems.
5. Officers who can work effectively with others.
6. Officers who are independent learners.
7. Officers who can apply their knowledge and skills to the unique tasks of the military profession.

The goal of introducing an "ill-defined" or "open-ended" project is to address outcomes 2 through 6: those objectives that reach beyond material content. Ill-defined problems, by their very nature, force students to reason and to think rather than simply memorize solutions. Moreover, these are exactly the types of problems that they will be faced with upon graduation. It's important that we start to develop these skills early on.

The Problem

> Your task is to help re-engineer a tension-link on the main landing gear of a Boeing 747. In accordance with Federal Aviation Administration (FAA) guidelines, the component must have a factor of safety (with respect to yielding) of 1.5, and the axial deformation must be limited to 0.225 percent of the original component length. An additional fiscal requirement imposed by the Air Force is that the link must be manufactured out of materials readily available at USAFA. The length of the tension link is 37.2 inches.

The student is purposely *not* given information regarding the material, the link cross section, the means of support (end conditions) for the link, the load it must support, nor how the load is applied. Rather, the students (divided into teams of three or four) are expected to identify what information they need to solve the problem and do the research required to answer these questions. The groups are not permitted to communicate with other groups regarding the problem, so they must come up with solutions within the group. A requirement for the groups or group leader to meet with their instructors on a weekly basis was imposed in an attempt to impart momentum toward problem solution.

The students are informed that the primary focus of the research effort is on the "design process" itself rather than the specific details of the technical analysis. The objective is to have the students frame the problem by asking a logical set of questions: "What is the function of the tension link? How is it connected to the subassembly? What type of loading does the link experience?, etc." To aid in the process, students are provided with a series of problem sets intended to get them thinking. The first problem set requires students to find and explain to another group member a published problem solving methodology, in the hopes that they will take a structured approach to solving the problem.

The instructor is directed to serve as a guide, prompting the students to think about what questions to ask and where to find information. When asked the right questions, instructors provide some of the necessary information, namely that the cross section is a hollow circular tube having a thickness of 1/8", the load is axial and tensile with a magnitude of 25,000 lbs, and that the end conditions are such that no bending moments are transmitted to the link. When the students ask what materials are "readily available at USAFA", they are simply handed a cylindrical tensile-test specimen and told that Academy has a number of tubes (of the specified wall thickness) made out of "this stuff". As of this point, the students still have not been introduced to the concept of material properties nor have they performed a tensile-test. The material specimen provided to each group could be one of six unidentified materials (two steel alloys, two aluminum alloys, magnesium, and brass).

Since it isn’t administratively feasible to have 200 groups performing tensile-tests at different times, one class period was set aside in the syllabus. Instructors encouraged students to get an early start on the project, so many of the fundamental questions regarding material and loading conditions were asked prior to the scheduled laboratory. During the lab, students record load vs. displacement data, develop a stress-strain curve, and calculate the modulus of elasticity and the yield strength of the material. These data are used to do the strain and factory of safety calculations.

Based on the information gathered about the tension link and the material, the students are expected to figure out that, given the restriction on link length and tube wall thickness, they must vary the diameter of the tube in order to meet the two independent requirements of maximum strain and factor of safety.

Throughout the process, as little information as possible is "freely" given to the group members --- they must ask for it or find it on their own. As a final product, each group is tasked to turn in a written technical report on their design, including such things as technical drawings, component weight and cost analyses, a discussion of manufacturing, assembly, and environmental considerations, and appropriate referencing of sources. A technical writing guide was provided to assist the students in writing their reports.

The project is not technically challenging, but is introduced prior to the classroom discussion on the relevant subject material. The goal is to have students reason out and ask the appropriate technical question just prior to receiving the related lecture material or, better yet, have the students reading ahead.

Student Reaction and Results

The typical USAFA cadet carries a high academic load (21 semester hours is the norm). In addition to an intensive schedule of physical and military training, programs such as soaring, parachuting, and T-3 (flight instruction in light aircraft) compete for the cadet's time. Ill-defined problems, by their very nature, require a substantial investment in both time and intellectual effort.

While many of the cadet teams were willing to "adopt" the problem, others were frustrated by the open-endedness of the problem. For these cadets, the missing ingredients in the problem definition were difficult to deal with. Interestingly enough, those who waited until the last minute did fine technically since all the relevant subject material was completed a couple days prior to the project due date. However, since their reports contained little on the design process, the final scores on these reports were justifiably low.

The reports turned in by the various teams reflected a bi-modal response in terms of level of effort. Many of the reports were excellent, including correct and well thought-out analyses and designs, thorough and correct assessments of their "mystery" material specimens, and color photographs. A minority of reports indicated a principle-of-minimum-effort approach that was very disappointing.

Some of the less technically inclined team's reports emphasized a checklist-style approach that ensured inclusion of all necessary topics, and all but ignored technical correctness. For example, all groups included the tension link diameter, but a handful of the 100-plus groups calculated absurdly large values for the diameter — with no comments as to reasonableness. Many failed to recognize that the maximum strain and factor of safety requirements were independent. A few, having recognized the independence of the two criteria, failed to choose the more conservative design of the two. Most of the technical transgressions were less blatant. Overall, even though there were problems with the quality of some of the reports, we were satisfied with the effort of the majority of the groups.

Instructor Issues

The cadre of instructors for this course covers a wide range of teaching experience, from first-time instructors to veterans of many years (including the department head and chair of the engineering division).

The introduction of this type of problem presented a significant challenge to the instructors. Some instructors cover as many as four sections (nearly 100 students) without “teaching assistants”, and the increased level of student interaction brought on by a problem such as this one can be very taxing. An instructor with four sections may need to meet with 24 group leaders each week, and the temptation to "give away" information to reduce the workload was ever-present.

For instructors who had taught the course many times, the inclusion of this ill-defined problem required more of an adjustment than for the four first-time instructors. Because the technical content of the course is very basic, class preparation time is minimal in comparison to other higher-level courses. The inclusion of this problem tended to increase the workload for all instructors, which was a source of tension.

During the period of the course when this project was under way, the weekly instructor meetings became lively forums of discussion of the plusses and minuses of the problem. A common theme was the frustration that, early on, few students seemed interested in collecting the necessary information, or even recognizing what was missing in the problem definition. As the project deadline neared (nearly a month was allotted for the project), a predictable deluge of questions began pouring in, compounding the frustration of cadets as well as instructors.

Grading the reports also proved difficult. Issuing a formalized "cut sheet" (defining specific numerical cuts for specified transgressions) on a project in which we ask the cadets to be independent thinkers seems somewhat hypocritical, but without such rigor it would be difficult to be consistent when grading 200 reports between a dozen instructors. To complicate matters, students submitted the reports only a couple days before mid-semester grades were due. As a compromise, a formalized cut sheet was generated; however, instructors were told to use the sheets only as a guideline and again reminded that the emphasis should be placed on the design/thought process rather than the explicit technical content. Instructors were not limited to grading the written report, but were encouraged to consider the group's level of effort over the duration of the project. Prior to grading, the instructors met to rate the general level-of-effort believed put forth by the student population and, based upon the discussion, a target average was established.

As expected from a first attempt at integrating ill-defined projects into an introductory engineering course, numerous problems were encountered. However, the results from this effort were sufficiently encouraging that this type of project will be continued in the future.

Future Offerings

The situation in EM 200 is rather unique in that every cadet, whether majoring in astronautical engineering or history (most declare a major in the midst of taking the course), must take this technical course. It would be interesting to see how our experience would differ in a course consisting of only engineering majors.

Current plans would be to include such a problem in future course offerings, though the specific details of the project will be modified each semester. Next semester, students will be asked to design axial cables (solid or chain links) to be used by helicopters to airlift large payloads.

Conclusion

As this is written, the semester is not yet complete, and the course critiques will provide more insight into how this problem was received and how the students perceived they benefited from it. Our perception was that the cadets fell into two fairly well-defined camps: those who adopted the problem and those who merely dealt with it. While the frustration of some the cadets was predictable, the impact on the instructor cadre was less so. Future classes of EM 200 will see ill-defined problems. Only through working such problems can the desired critical thinking and problem solving skills be developed. The subjective grading aspects inherent in this type of problem are expected to be a continuing challenge.