Integrating Problem Based Learning into the Classroom via a Real-Time Ship Engineering Problem

John W. Bridge  
Assistant Professor in the Engineering Department, Maine Maritime Academy

Stephen Collins  
Professor in the Engineering Department, Maine Maritime Academy

ABSTRACT

An actual engineering problem encountered during the annual 2006 summer Training Cruise at Maine Maritime Academy was brought into several courses and used as a vehicle for student learning while simultaneously providing a viable student-designed solution to the problem. During the Training Cruise, a request was made to re-design and machine a new trolley hoist bar to allow for additional clearance for easier access to work on the ship’s engines. A midshipman took the existing hoisting bar, which has a 2-ton lifting capacity, and machined a replacement that included a significant change to the geometry. This replacement part was not used during cruise. After cruise, preliminary stress analyses showed a significant deficiency in the part and the instructor of the instructor of the Strength of Materials course decided to allow the students in the Fall to analyze and compare the original and replacement bar for load and stresses. The final “mini-capstone” project for this course was for student teams to analyze the original and midshipman design, and to come up with a new, more robust design. Concurrent with this class, students in the Fall Welding class investigated welding concerns with a suggested “fix” to the re-design. This hoist bar project is being carried on to the Spring Materials Engineering classes as well. Material samples will be tested to failure and the processing of the steel will be addressed. The Spring Welding class will also be given a revised assignment of the problem including a “fix” from the Materials course to see if a different problem format will give better results. Finally, the Spring Computer Applications class for Engineers will model this bar using a CAD program and upload the drawings into a finite element modeling program to check for stresses and deflections. Time permitting, potential re-designs will be computer-modeled as well.

KEYWORDS: Problem Based Learning, Maine Maritime Academy, Trolley Hoist Re-design
Introduction

During the annual Maine Maritime Academy (MMA) summer Training Cruise on the Training Vessel State of Maine, an engineering issue came to light that would provide an instructive problem-based learning exercise for four engineering courses. The problem involved a potentially serious safety issue in which a trolley hoist bar was redesigned and machined for use in a 2-ton rated hoist assembly. There was an engine clearance issue and the intent of this redesign was to eliminate the hook and hanging ring connection to raise the assembly approximately 5 inches (Fig. 1).

Figure 1. Original and Midshipmen Re-Designed Hoist Support Trolley Bar
The re-designed bar with increase in clearance would significantly facilitate the maintenance and repair of the engine heads and other engine components. However, the ship’s Chief Engineer had concerns with the redesign and did not install the re-designed bar. Instead, after the cruise (at start of the Fall semester) he asked a few MMA Engineering Department faculty inspect the re-designed bar.
After a preliminary stress analysis it was determined that the bar was deficient and the Engineering professors involved thought that this would make an excellent teaching tool in the classroom. The Chief Engineer also expressed a desire to find a timely solution to the problem and welcomed a student-led design.

Since the strength of the bar was in question, the problem was introduced to the Strength of Materials (SOM) technology classes and to the welding classes during the Fall term shortly after the problem was identified. The engineering materials course (Nature and Property of Engineering Materials) and CAD modeling class (Computer Applications for Power) were also identified as Spring courses that would benefit from this ship problem-based learning exercise.

The objectives of this problem-based learning opportunity were four in number:

1) To provide another means to increase student learning of class concepts
2) To excite students by connecting them to a real-world maritime application
3) To provide a bridge to connect several other engineering courses with a common project
4) To come up with a viable student-based solution that could be incorporated on the ship.

**Problem - Based Learning Application**

**Strength of Materials**

The SOM instructor decided to use this problem as a final design project for the course assigning it a 10% course grade weighting. There were two sections and all the students were seniors. This final design project was not initially part of the course syllabus since the Engineering Department was not notified until after the semester start, but the students were not averse to the project. The students were in their fourth year and had already experienced engineering design projects in other classes, so the teaching approach was to put the burden on the students to accomplish the project. They were expected to conduct the various project parts in a reasonable, planned-out manner—applying what they were learning in the course, real-time, to the specific tasks of the project with limited guidance by the instructor (explained below). Only one progress “report” in the form of an initial bending analysis and drawing was required of the students prior to the report submittal.

The project was verbally related to the students immediately after the decision was made to incorporate the problem, but complete details were withheld since 1) the problem still needed to
be put into project form and 2) it was decided to wait until the basics of axial, shear, bearing, and torsional stress were addressed in class—just before bending stresses (midpoint of the course).

The project handout specifically tasked the students to do a thorough engineering analysis for the original design, the midshipman’s redesign, and for a new design. The students worked in teams of two. Below is a list of the specific engineering quantities the students were asked to address:

- Component loads expressed in detailed Shear and Moment Diagrams (make simplifying assumptions) for original beam shape and recommended re-design (if new shape) based on a maximum hanging load of 2-tons.
- Normal stress, bearing stress, bending stress, direct shear, torsional shear, buckling, etc., as required.
- Combined normal and shear stresses as applicable (axial, bending, torsional, transverse)
- Beam deflection (and concerns)
- Ductility considerations, corrosion and other mechanical and physical property limitations.
- Material selection recommendation
- Include pictures, detailed sketches, free body diagrams, etc.
- Include all assumptions.
- Calculations can be done neatly in pencil and provided in appendix.
- If computer analyses are performed, cite equations that are used. You may sketch the bar designs by hand, although use of computer aided design (CAD) software such as Key Creator is encouraged.
- Justification of your new design, showing functionality and vertical clearance improvement over the original design (this item later added verbally to project)

The 2-ton amount is what the hoist assembly is rated for and this load is not uncommon during routine maintenance operations. The students were also taken to see the original hoist bar as situated in the hoist assembly inside the training ship’s engine room. Some of the students had actually used the hoist assembly during previous cruises and/or during training.

Though the students were told that the burden was on them to organize and do the analyses, the instructor did refer back to the bar, as each major applicable subject area was addressed in class, and asked the students how each lesson’s stress problem-solving technique applied to the hoist bar. Students were encouraged to ask questions during class and during office hours concerning the problem. Most of the general tasks above were discussed in class (and in their
books) except for beam deflection, corrosion, and the computer aided modeling. The combined loading task would take a little more thought and investigation by students to accomplish. However, there were sufficient class examples addressing the various stress concepts so that students could assimilate the concepts and apply them directly to this project. As described in their project handout, very specific guidelines were given for the actual formatting of the technical report and at the end of the course; each project team was required to give a 5-minute presentation on their project to the class and the training ship’s engineer.

**Welding Course**

The welding instructor adapted this problem to the freshman/sophomore-level students in his class, most who had not yet taken any engineering courses (there are no engineering prerequisites for this course). His task centered on making the midshipman’s re-design safe by welding steel plates to the sides of the hoist bar. He kept the same general design parameters as listed in the project but provided to the students the effective reduced cross-sectional area and amount of steel plate necessary to carry the 2-ton load.

The problem was framed as an online discussion assignment. Online asynchronous discussions are assigned almost every week in this course, and it was in the twelfth week of the semester, so students should have been comfortable with the technology. There had been several previous discussions in which students created or modified drawings.

The assessment description was given in two parts: first, as an HTML page with a general description and a link to a detailed problem description with drawings and photographs. The two of the objectives of the course for which the assignment was designed were for the students to be able to read common welding symbols and to become familiar with common weld joint designs. Analyzing the forces in a beam under load and designing a weld repair accordingly was outside the scope of this course and not an objective. Consequently, the problem was simplified so that only shear forces in one direction were considered, and examples were given showing how to calculate the effective cross sectional area of repair bars and the effective throat of fillets and groove welds. Essentially, the only concepts being assessed were the application of a variety of weld joint designs, and the symbols for them.

The following was the initial direction given to the students:
• Devise a repair by adding plates, round bars, angles, or other stock along each side to replace the cross sectional area removed by the center hole. You may draw your repair by adding to Fig. 2 (next page) or create your own drawing. The design has been simplified here to a straight bar to make it easier to draw your repair.

• Show any weld preparations, such as bevels.

• The hole must stay open to receive the hoist pin.

• The overall height (1.25" shown above) of the bar may not be increased more than ½" above and below the existing bar (or, max. = 2.25" height).

• Draw a weld symbol pointing to the weld locations and showing the type, size, dimensions, process, pitch, bevel, and/or other information about the welds you will use. See examples (in course text).

• Remember, your welds must have at least as much effective area as the missing metal (1.50 sq. in.) but your repair plates may have more. Some examples of ways to calculate effective areas of single welds are shown in Fig. 3. (This assignment assumes only shear is necessary for calculating effective throat and area. Bending moments have been disregarded.) Your repairs will probably be welded top and bottom on both sides, making four welds (simply add their effective areas together), although you may propose other alternatives.

• Do not use a weld joint already posted by another student.

• See the Topic for requirements for your discussion message.

• The drawing on the page below was made using a .06" grid. The grid may be made visible by selecting “Draw” (on the Drawing toolbar at the bottom left), click on “Grid” and “Display gridlines on screen.” You can zoom in by clicking on View in the toolbar near the top of your screen.

• Or, you may print the drawing and draw your repair and symbols and then scan it. Do NOT post .bmp files, they are too large; set your scanner to make jpg or jpeg files, or convert your .bmp files by opening them in Window “Paint” and “Save As” jpg file type.
For the Nature and Properties of Engineering Materials course, the metallurgical aspects of this bar will be addressed. A majority of the SOM students are required to take this course in the Spring term so this is a natural follow-on to the stress analyses already accomplished by the
students. Many materials engineering concepts such as stress and strain, ductility, and weldability were introduced in SOM and Welding courses and this course elaborates on these concepts and introduces new ones as well such as fracture toughness and fatigue.

In the first part of the course when general material properties are discussed, students will take hardness measurements of this hoist bar and be able to calculate a rough yield strength for this steel bar. In a later lab when stress and strain are addressed in more detail, the students will be given the bar to fit with strain gages and asked to load the bar to failure in the materials laboratory tensile/compression testing machine. From the failure load, the students will be able to figure out a more accurate strength for the steel and estimate the general carbon content (the alloy of the midshipman re-design bar is unknown). Following this test and later in the semester, the MMA machine shop will machine standard 0.505 inch diameter, 2-inch gage length tensile test specimens, which student teams will load to failure. From the load and deformation data, students will calculate the corresponding stress and strain curve and calculate a much more accurate yield strength, ultimate strength, modulus of elasticity, and percent ductility. The students will find that the latter test will much better characterize the material’s strength, type, and alloy.

Computer Applications

For the Computer Applications for Power course, there are 11 computer projects that students accomplish. Two of these will involve the hoist bar. One project will be for the students to make a technical computer aided drawing (CAD) of the bar by taking physical measurements of the actual bar. The second project will be taking their CAD drawings and uploading them into a finite element modeling (FEM) program which, if done properly, should give very accurate quantitative stress and deflection data for the bar. This information can then be used to further validate the empirical data found in the engineering materials class and the analytical calculations conducted in SOM.

Problem-Based Learning Results for SOM and Welding Courses

It was difficult to directly measure how successful the hoist bar project was in helping to achieve the learning objectives of the course, but observations could be made about the general quality of the reports and level of understanding of SOM and Welding concepts inherent in them.
Of the 15 SOM reports that were accomplished, the majority of them met the basic objectives of the project. One was hastily put together and did not follow the format instructions, but even this one used the basic stress analysis equations correctly though did not include shear and bending (V&M) diagrams. All of the other reports achieved correct shear and bending moment diagrams. It was interesting to note that all the projects did calculate the major stress mode (bending) for all 3 designs (though a few had major errors). Six (40%) of the reports performed only this bending analysis and neglected bearing, shear, and torsion. It is true that the key objective was to ascertain if the designs were strong enough to sustain the loads safely, but it seemed as if the majority of the groups did not carefully address all the specific items that were mentioned in the project handout. Only 3 of the 15 projects found all the required engineering quantities to include combined loading and beam deflection. These two topics required independent reading by the student, though the information was in their textbook. On the other hand, it was encouraging to note that almost half of the projects utilized a CAD program to sketch and dimension the hoist bar to scale (not required).

With regards to creativity, most the designs played it safe and either beefed up the original design, though this did not improve the clearance issue, or modified the midshipman replacement design to make it more robust. All of these designs chose a higher strength alloy. Five designs were significantly different from the original and midshipman-designed hoist bars. Three of these designs are shown below in Figure2. The simplest is the rectangular block. All of these designs can easily handle the 2-ton load, can be made of low carbon steel, and have large factors of safety—perhaps even over-designed.

With regards to functionality, several of the student designs would work in the ship’s hoisting assembly, the ones with the most clearance and ease of fabrication will be chosen by the ship’s engineer.

It is apparent that several of the teams started very late on this project from the comments received by the instructor from several of the student teams. Also, it was not until the last two weeks before many students came by to seek assistance from their instructor.

It should be noted that from both verbal and written end-of-course comments, the students really enjoyed doing the SOM project, and it easily ranked the highest of all the activities done in class.
In the welding class, the students received the project in the 12th lesson of the course and, as a whole, never fully mastered the project. Some of the responses to the first assignment of the problem were very good, as shown in student drawings in Figure 5 (in this figure, the feedback from the instructor is superimposed on to the student drawing).
Figure 5. Student Drawing: Good response to First Welding Assignment

Unfortunately, such good results were in the minority. Many students had difficulty with the basic concept of how to make the repair. Many more were unable or unwilling to do the assignment at all. Weekly discussion assignments were given only 4 possible points out of 440 possible for the course. The instructor observed these results, and revised the assignment and reassigned it the following week for an additional 4 points. The revised assignment included several more detailed examples of how to perform the repair and a template to be used by the students. The instructor
hoped that the template would make it clearer what results were to be reported (additional effective cross-section area, weld effective area, and welding symbol) by using a “fill-in-the-blank” approach. Unfortunately, by now it was the second to last week of the semester, and, once again, the assignment was only worth four points, and it coincided with a week in which there was a written test in class on several weeks of course content. It was too late to change the weight, and not enough time remained for further discussion, in class or online.

There were a few responses to the reassignment, some quite good. One student who had posted three previous attempts at the first assignment finally got it on the reassignment. However, he did not fill out the template because he was still challenged by the use of the MS Word drawing tools. Another student who had been entirely unable to do the problem in the first assignment did make good use of the template in the second assignment to finish the assignment successfully. Unfortunately, in all, there were only six responses to the reassignment from the 50 students in the course.

**Recommendations**

With regards specifically to the SOM course, and in general to implementing this project into future courses, it is strongly recommend that firm, detailed progress reports be required by the students throughout the semester, and that these progress reports be made a substantial portion of the overall course grade. At the very minimum for the SOM project, an early conceptual design submittal that includes three brainstormed re-designs, a preliminary stress analysis midway through the semester, and a final, detailed stress analysis two weeks before the project is due would provide incentive to the students to focus early and to be thorough. A draft paper submittal might also be a good idea if the instructor has time to review them. Also, the project’s overall course weighting should be increased to at least 15%.

Reflecting upon the semester, the SOM instructor would also, to a greater extent, let the hoist bar (or whatever problem-based learning example is used) drive or “drive home” the learning in the classroom. For example, when introducing shear loads and stresses, instead of just mentioning to the students that they should “think” about how shear forces act upon the bar, the students should be tasked via an in-class problem or homework problem to apply shearing concepts to the bar. More aggressive tactics should be used in all applicable learning opportunities such as finding centroids of cross-sections, determining neutral axes, finding bending stresses and bending-induced shear stresses, etc. Perhaps adding these opportunities as part of their daily homework or problem set submittals would be beneficial.
With regards to the welding course, several lessons were learned by the instructor. First, problem-based learning requires at least two assessments: a formative and a summative. If students had been given detailed models of the expected answers in the first assignment, they would not have had to search for methods to solve the problem, but some were so lost that they did not understand how to make the basic repair. A fine balance is required.

Second, problem based learning takes more effort by the students, so like that mentioned in SOM, grade weight must be commensurate. With insufficient weight for the grade, many students chose to skip the assignment, especially the second time around when they had already become frustrated by the change in learning style and perhaps in misunderstanding how to make the repair.

Third, the problem should be appropriate for the objectives of the course. This was an ideal problem for a Statics and Dynamics course, or a Materials course with students already versed in statics and dynamics, but simplifying it for use in an introductory course required a lot of instructions and examples. In the process of simplifying it, the assignment just became too long and too difficult to read.

In summary for the welding course, although the instructor and a few of the students had a valuable learning experience, far too many of the students either skipped the assignment or became frustrated trying to complete it. The instructor has some ideas for simplifying the problem even further that include simply specifying on the template the location and shape of the repair bars on each side of the trolley bar, and having the students specify their choice of weld design. They would only have to calculate the weld sizes to put on their weld symbols based on the effective weld area.

For both SOM and welding courses, a major reason that both instructors did not incorporate the project more fully into their courses, was that their courses were already full and most lessons did not have much time or any extra time at all to include daily discussion of the hoist bar “connection”. At this institution other commitments such as STCW and OSHA requirements reduce available time. For problem-based learning to take a larger role, a decision should be made before the course start (and not afterwards as demonstrated in this paper) to structure the course to allow for problem-based learning to occur, particularly at the critical learning junctures.
Conclusion

Despite some of the time-related shortcomings in applying this problem-based learning opportunity in the classroom, the students did enjoy this project and did achieve the overall basic objectives of learning stress analysis and welding concepts while simultaneously exercising engineering judgment and creativity. This project was one that the students could relate to and immediately apply engineering concepts to. It also provided an avenue where several courses could share many aspects of the project and collaborate via student continuity and interaction on finding key material property values. Finally, several innovative designs were created that met both strength and clearance requirements. They are strong candidates for replacing the current hoist trolley bar.

Authors

John W. Bridge is an Assistant Professor in the Engineering Department at Maine Maritime Academy in Castine, Maine and is a registered Professional Engineer. He served for over 20 years in the U.S. Air Force as an aerospace research and development engineer and retired as a Lt. Colonel. He has taught mechanical engineering at several institutions including the U.S. Air Force Academy and the U.S. Military Academy at West Point, New York. He can be contacted at john.bridge@mma.edu

Steve Collins is a Professor in the Engineering Department at Maine Maritime Academy in Casine, Maine. He teaches welding and he is a Certified Welding Inspector. He has a Master’s in Adult Education and Distance Learning. For 25 years he worked in ship and power plant construction, and has been teaching at MMA for 15 years. He can be contacted at scoll@mma.edu.