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Integration of Safety Concerns and Societal Impact as Learning Outcomes of Mechanical Engineering Courses

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Abstract : For many homework, mini and final projects in all the courses that the author taught since the last more than 5 years, the students were asked as a part of course requirements to include critical real life examples, and a discussion of how poorly designed mechanical components or subsystems can cause safety concerns and affect the society at large in one way or the other. These requirements partially address some of the students' outcomes under General ABET's Criterion 3. Of particular interest are the students' understanding of the professional ethics (outcome 'f'), and understanding the impact of engineering solutions and how they impact the society (outcome 'h'). In order to help in identifying some of the real life engineering components, the author showed online videos and also used "Touch and fell" (T&F) idea in which some of the failed or non-functioning engineering components (shafts, bearings, bolts, etc.) were brought to the class to do first order reverse engineering (reconstruction of failures using mechanics approach). While few junior and senior level textbooks in the Mechanics, Design, Thermal Sciences and Production areas do include few worked examples and exercise problems based on real life industry applications, they do not generally include a discussion based on the final results from ethical or societal impact points of view. Also, most chapter-end exercise problems are usually structured based on directly using concepts and formulas from the chapter and not necessarily require a realization of real life applications of such problems. Usually, this may be beyond the scope of some classes, or, it may be perhaps due to the time constraints faced by instructors, or, due to lack of maturity level of students. Similar is the experience with the open-ended mini-projects such books may suggest. On another issue, some of the instructors may not have enough industry exposure to think of real life applications of homework problems and project assignments.

This paper presents the teaching and learning (T&L) experiences of having the students include real life engineering examples for few homework problems, mini and final projects. Ethical issues are not directly covered in this paper. The examples should be critical or important in nature and required the students to include a discussion of the implications of how poorly designs can impact the society in one way or the other. In many cases, a redesign was not expected unless it is a final project. This approach is somewhat similar to case-based learning (CBL), which is mostly used in medical, civil engineering, and other fields, but seems to be not so much used in mechanical engineering. In order to help the students appreciate the seriousness of the philosophy proposed by the author, few engineering case studies were first discussed in the class. Discussion of engineering case studies aid them understand the importance of how

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poorly designed thoughts, ideas and actions can affect the lives of many. For example, while covering the fatigue design of fasteners topic, case study of an accident that occurred in 2009 at Sayano–Shushenskaya hydroelectric power station (in Russia) was discussed. Similar ideas have been included in other courses such as: mechanics of materials, machine design, finite element analysis and mechanism design. Students although struggled in the beginning to appreciate the idea, were able to come up with more appropriate real life examples for several homework problems, mini- and final projects. The main assessment tools were their grades in homework and project reports together with the learning outcomes that they documented in the reports. Students' feedback using a combination of Likert Scales and questionnaires show that majority enjoyed the approach adopted in learning the subject matter better. Also, the student perception indicated that their ability to think logically improved with this approach. Further, engineering reasoning and judgment, interpretation of results and how the designs can affect the society were also appreciated. Few sample examples and experiences from the different courses will be presented in the paper. More examples will be covered and shared with the interested participants at the conference.

Background information and review of literature:

In a view to elevate students' critical thinking levels when solving the in-class or homework problems, many instructors strive to follow Bloom's pedagogical approach [1], in addition to beginning with a 'traditional approach' (remember, understand and use formulas to get an answer). Assigning homework problems and projects majority of times using a traditional approach puts the knowledge domain at the bottom half of the Bloom's pyramid. It may create gaps and deficiencies in understanding, analyzing, and evaluating the implications of the solutions in a global perspective, which are at the higher levels of the learning pyramid. Usually, several courses in an engineering program collectively satisfy to a greater extent many or all of the ABET's "General Criterion 3. Student Outcomes" [2]. Capstone courses are expected to enhance the teaching and learning (T&L) experiences to higher levels of the learning pyramid. How can we incorporate such experiences in all core courses we teach? There are numerous papers on T&L [for example, 3], Problem and Project-based learning (PBL), for example [4], Case-based learning (CBL), for example [5, 6], and other Active learning techniques such as Cooperative and Collaborative techniques [7, 8] are available for, and being adopted by many instructors as T&L strategies to motivate and to engage students to learn the subject matter better. Wankat's paper in particular [3], discusses techniques in detail to deliver the lectures, and for the students to learn the course material more efficiently and effectively. The tips provided in this paper can be used in these modern times and in a more effective way due to availability of updated and upgraded classroom environments.

Many US and other universities around the globe also have some form of Centers to promote teaching and learning techniques to provide faculty and students with a relevant opportunity to see theory in practice. It is shown that using PBL or CBL techniques engage students in discussion of specific scenarios that resemble or typically are real-world examples [5, 6]. This method is learner-centered with intense interaction between participants as they build their knowledge and work together as a group to examine the case. The instructor's role is that of a facilitator while the students collaboratively analyze (similar to Collaborative Learning) and address problems and resolve questions that have no single right answer (open-ended). Problem based learning (PBL) is considered the founding paradigm that models such as CBL have been based upon [7, 8].

Williams [9] discusses that CBL approach is being extensively used and evaluated in medicine, veterinary science, dentistry, nursing, senior care and other areas, but lacks in the adoption and evaluation of CBL prehospital education. Also, he observes that while there is a plethora of literature on PBL within many different disciplines, however, there is a paucity of literature within the contexts of prehospital education. There are several other studies on CBL approach as used in business, law and medicine areas [10, 11].

Figure 1 (redrawn) shows how PBL and other T&L approaches are connected to each other [12]. In CBL approach, usually a case is established first and the group analyzes it using brainstorm method. This is followed by formulating the learning objectives by the group, documenting and dissemination of their findings with the class. The final stage is to find areas of improvement before the solution is implemented in to practice. In looking at the literature, it appears that use of CBL approach for teaching mechanical engineering courses, particularly at the homework solving level seem to be somewhat not practiced. However, since CBL is a subset of PBL, plenty of literature is available in supporting the use of PBL and other active learning techniques for project assignment and for capstone classes.

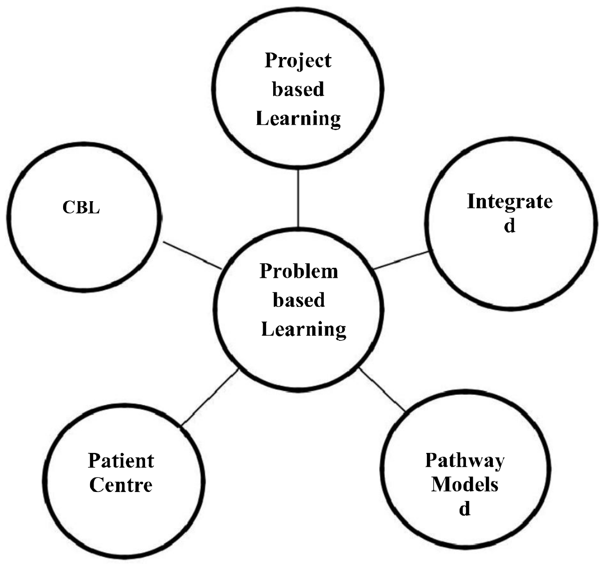

Figure 1: Educational Fusion of Problem-Based Learning (PBL)

Foster [13] developed a sample workshop on how cooperative learning techniques are related to The Learning Pyramid shown in Figure 2 [14]. The pyramid shows that cooperative learning is associated with higher retention of knowledge and improved student learning. Wankat's approach [3] is similar to Foster's in which teaching and learning can be improved efficiently and effectively by following the course preparatory tips and implementing the active learning ideas in the class rooms.

It is well recognized that the instructors can improve the course material and delivery by continuously designing and updating the content and making use of new instructional materials and methods that motivate and engage the students to assume the responsibility to learn the material efficiently and effectively. Although a detailed PBL or CBL approach is not carried in the work presented in this paper, the author lead the students to examine the data given in several in-class and homework problems and identify the real life applications and address how the design (based on calculations) may cause safety concerns (if poorly designed), and can impact the society in one way or the other.

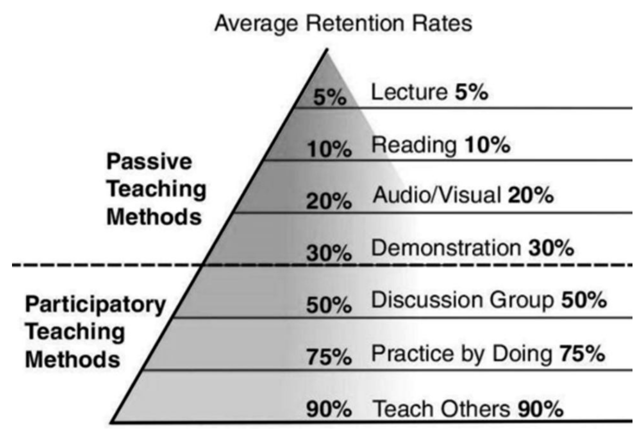

Figure 2: The Learning Pyramid [14]

Examples and assessment tools used and the learning outcomes

As mentioned before, besides incorporating some of the teaching techniques such as PBL and ACL, the author also used the “Touch and feel” (T&F) idea in which several relevant engineering components that have failed or broken in service have been brought in to class rooms for the students to actually see, touch and feel them, and for further group discussion. The “Touch and feel” (T&F) idea is not really new as many instructors strive to bring real components to the classrooms for promoting active learning environment (ACL). Sometimes this rich experience is supplemented in the form of laboratory experiments. Example components for the T&F experience that the author used were: gearbox shafts, small machinery casings, pulleys, gears, fasteners, bearings, connecting rods, etc. Many of these components have been donated by the industries (due to co-op connection the author through the university has), or brought by the students from their own vehicles or from other equipment (lawn-mowers, etc.). While few of these components are brand new, many others are 'failed' components, in the sense that they are completely fractured in service, or deformed permanently. 'Learning from failures' is an important activity in the learning pyramid that enhances higher levels of critical thinking skills among students.

With the real life components presented in the classroom, students were asked to 'reconstruct' (reverse engineer) why such components might have failed. This included an estimation of load calculations (Statics) and material identification (steel, aluminum, etc.) to determine the safety or no safety factor(s) (using mechanics of materials and machine design concepts). The geometry of critical areas where failure originated on the failed or broken parts has to be identified and measurements taken if needed using geometric and other metrology instruments (Vernier calipers, etc.). This information is used to perform calculations based on static and fatigue failure theories. Performing CAE studies (CAD and FEA) was expected in some cases to handle the complex geometries and loads. Such problems were assigned as a group task and as mini-projects. Carrying further, for the report, the students were expected to discuss the impact of the poor designs (based on results obtained) on the society in one way or the other. For example, an over-loaded or over heated piston seizure in an engine while traveling on an interstate can cause traffic slow down, jams, or even cause accidents. Traffic delays can cause shipment delays carried by the heavy trucks on the road, or affect the life and quality of perishable goods being shipped. Another example can be that component recalls (due to poor designs) can cost both time and monetary losses, as well as affect reputation of the companies.

Showing real life engineering components in the classrooms when possible enhances students' motivation to think and improve ability to connect what is taught in a classroom with what they observe in real world engineering applications around them such as small machinery (lathes, milling and drilling machines, tall sign posts, bridges, etc.). These experiences in turn pave the way for them to think positively to search for real life engineering examples and applications of the assigned homework problems or projects. It also improves their sensitivity to understand the role of dimensional tolerances in assemblies. Thus, with a little bit of effort and motivation on their part, many students felt it easier to connect the in-class and several homework problems with possible critical real life application(s).

A. Example of homework problem in Statics course

As an example, in the statics course that the author taught using the traditional approach of solving the well-defined numeric problem on frame shown in Figure 3 [Ref: 17], students used the equilibrium concepts and free body diagrams to solve it. The solution involves determining the reaction loads and the force at each joint. In the traditional approach, students use the "Concept-free body diagrams-data substitution in the formula-solution", without paying much attention to the given dimensions of the frame and the magnitude of the given load (P = 240 lb), to interpret the results obtained. Since this is statics course, it may be argued that neither real life applications nor safety concerns may be expected as a

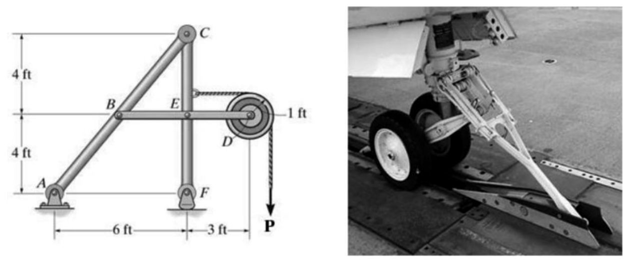

Figure 3: 3-member frame and a possible real life application [Ref. 17]

part of the course. However, to enrich their thinking skills, real life applications of the frame and their safety concerns are discussed. One such application is the catapult frame used to launch military planes from a ship. This is shown in Figure 3. Although neither the geometry nor the loading conditions exactly correspond to the conceptual diagram shown in the figure of the given problem, it enhances and encourages the students to search for more similar applications which help them in the follow on courses to perform more rigorous analysis. The student feedback has been encouraging.

The fully deployed landing gear of an airplane

Figure 4 :Example of landing gear and its safe design concerns [Ref. 17]

(shown in Figure 4) is another example of a frame that the students can cite, although a landing gear analysis is more complicated, as it is a mechanism. The second figure in this shows a failed system in fatigue. This demonstrates the need for students to understand how unsafe designs impact the society at large. There are several such real life engineering examples that if discussed as a part of in-class and homework problems, elevates the critical thinking skills of students. Interested students and instructors can revisit some of these examples in follow on classes to perform advanced analysis.

B. Example of homework problem in Machine Design course

As an example, in the machine design course that the author taught using the traditional approach of solving well-defined numeric problems ("Concept-data substitution in the formula-solution"), it was found that the students' understanding and feel for the given data and the numerical answer was lost. They merely understood the problem definition, the formula to be used and to obtain the correct answer after performing calculations. Although normally it is expected to interpret and discuss the results obtained, they seldom paid attention to this aspect. When the same problem was made open-ended, the students engaged themselves to think of a real life application first to assume the missing data appropriately from among many available choices and perform engineering calculations to obtain a solution to the problem. In this way, they defined their own problem and data to obtain a solution.The course learning objectives (CLOs) of the Machine Design course are:

1. Develop, set-up, and solve mechanical component design problems based upon given data and requirements.

2. Develop corrective action (define the cause for a problem and the design fixes) for field problems.

3. Understand the need for proper design actions via discussions of current, news worthy, design related incidents.

4. Through mechanical component design homework and team-based problems develop an appreciation for design tools and the ever-changing materials, processing and analytical techniques available to design while providing an understanding of the basics of design.

The problem used for illustration is selection of a rolling contact bearing and gear tooth analysis of a simple geartrain system stated as follows:

Problem statement:

a) Determine the dynamic load rating of a ______ type of rolling contact bearing needed to operate a simple geartrain consisting of a spur gear and a pinion. The industrial application where the bearing and the gear pair to be used corresponds to ________, which require a minimum design life of _______ hours.

b) Determine the power requirements of the system based on bending and contact fatigue lives of the gear set. Assume a suitable safety factor and all other parameters based on the application you assumed.

c) Based on the results obtained for your specific application, discuss the safety issues and any potential impact on the society, should such components fail.

The above problem was assigned as a group task in which the students were to think of a real life application first and work backwards to find potential solution(s) to the problem. The following short email communication (slightly edited) between the students and the author helped them understand the connection between the bearing selection and the gear design of the system.

"Hi Professor,

I know you highly encouraged us to use our book, notes, and the internet, but I can't seem to find information for one part of the gear question. I understand most of the data that we have to assume and justify based on our chosen application, but the assumptions that are prompted as 'The industrial application where the gear pair is to be used corresponds to ________, which require a minimum design life of _______ hours'. I know that once I figure out hours and assume an rpm I can figure out loaded cycles and use that to find Yn and Zn, but I'm not sure where to find those two blanks really".

I understand if this is something you can't answer, but if there is any direction you can point me in it would be greatly appreciated. I'll continue looking through the book and Shigley handouts.

I may be over thinking it too, it tends to happen.Thank you for your help and consideration,

Students of group 2"

My reply to the above was: "There won't be any single answer to that. But the argument is similar to the life of bearings. You want it (the bearings) to last certain (finite or infinite) life. You make it up for the real life application you had in mind and do the calculations."

Student: "ok that makes sense, thank you!"

My continued response: "Here is general info from Shigley from bearings chapter (that I might have uploaded under bearings on BB) and/or given as an in-class handout. But this is for bearings and for generic applications (not specific). For example, 'Machines for continuous 24 hours service' is a generic statement, but you need to find out and justify what are those machine systems are that require 24-h service. Can you think of any? Any case, similar argument works for gears also depending on specific real life application that you choose."

My continued response: "Don't change your work based on this email unless your solution is way off. Also, do not pass this information to others - it may create confusion as their solution may be completely different due to a different real life application they chose."

I emailed them the data table from Shigley book as shown below [Reference 15].

Based on the tabular data such as the above, the students chose different critical real life examples

Rolling-Contact Bearings | 583

Table 11–4

Bearing-Life Recommendations for Various Classes of Machinery

Type of Application	Life, kh
Instruments and apparatus for infrequent use	Up to 0.5
Aircraft engines	0.5–2
Machines for short or intermittent operation where service interruption is of minor importance	4–8
Machines for intermittent service where reliable operation is of great importance	8–14
Machines for 8-h service that are not always fully utilized	14–20
Machines for 8-h service that are fully utilized	20–30
Machines for continuous 24-h service	50–60
Machines for continuous 24-h service where reliability is of extreme importance	100–200

Ref: Shigley's Mechanical Engineering Design, 9th edition, McGraw-Hill [15]

such as air conditioning equipment for hospitals, office buildings, hotels and similar, which require almost continuous operation. Therefore, they assumed the expected bearing life value between 50 and 100 kh for further calculations. Other students assumed the data corresponding to machines for intermittent service and operation, such as those used in recreation boats, precision lathes, drilling machines, etc., used on typical shop floors of manufacturing companies. Students also designed the mating shafts and other components in the assembly of the assumed system. These are carried as mini or as final project for the course. Implications of poor or failed designs and their impact on the society are realized and discussed in their report.

Simple example such as the above provided the students to think of real life applications while solving in-class or homework problems in these and in all other topics of machine design course. Since the students have experience from their co-op training, it didn't take much time for them to think of such practical applications. They also understood the design inter-relation between different components that forms an assembly of a system or a subsystem. They realized that any design changes made to a single component of an engineering system can affect the design and performance of the other. Math tools such as Excel, MatLab, etc., enabled them to perform parametric studies to obtain different designs of a system that correspond to different real life applications. Overall, the students' feedback collected in the form of surveys or as learning outcomes that they documented in the report and mapped with the CLOs have been very good although some found it is a challenging task, or felt it is an unnecessary expectation to do for every or for group of homework problems.

C. Example of homework problem in Applied Finite Element Analysis course

Another simple example presented in this section further illustrates the ideas presented in this paper. This is one of the many examples from the finite element analysis (FEA) course that the author taught several times over the years. Finite element analysis is an elective course offered at the mezzanine level so that both the senior undergraduates and graduate students can take it. The following problem from Logan's textbook [16] is assigned. There are many textbooks available on this subject with some at basic level while others with material coverage at an advanced level. Due to the nature and maturity level of the students taking this class, it was decided to use

Logan's textbook for the course. Many examples and exercise problems presented in this book and in other similar books are conceptual in nature to reinforce the fundamental concepts covered in a basic FEA course. Thus these books do not discuss about the real life industrial applications of the worked examples or the exercise problems. It is a matter of once own choice whether to expect exercise problems based on real world applications, or just accept if they cover concepts only. Even if there are few exercise problems that are based on real life applications in these books, usually they are not open-ended problems requiring a discussion of possible redesign or to discuss safety issues and possible impact on society should the results so indicate.

In the past, the author did not stress much on the industrial applications of the assigned homework or class work problems. Therefore, whatever (correct) answers they obtained to a particular problem were acceptable for full credit. For the mini-projects in the FEA course, normally larger number of nodes and elements were expected to be used in 1D and 2D modeling, and the results compared for convergence with simplified smaller models. Since the solution to the larger size models involve assembly of a number of symmetric matrices and to perform the required matrix operations, students learned more programming skills while using a math tool (such as matlab, excel, etc.) to solve such problems. For the final project, a combination of 2D and/or 3D CAE simulations have been used for handling more complex geometries, loads and boundary conditions. They compared the results from these models with simple hand calculations using mechanics and machine design formulae. Some of the problems faced with the final project were the learning curve to use the available CAE tool (NX 9.0) which quite a few students were not familiar with. For FEA course, usually an acceptable way to organize and to teach the course is to solve conceptual problems using simple models without regard to paying much attention to the numerical values obtained in the solution to those problems, or to worry about real world applications of those problems.

Problem statement:

Determine the static deflection at locations (nodes) 3 and 4 of the 3-spring system shown in Figure 5. Use direct stiffness method. While solving this problem, the students are asked to make an attempt to cite real life application(s) that closely match the data given in the problem. Safety issues and potential impact of poor designs of the application considered are also expected to be included. Finally, the learning outcomes of solving this problem and how they map in to the course learning objectives (CLOs) given in the syllabus are also expected to be attempted as a part of the solution to this problem.

The first step in the solution process involves formulating the equation based on nodal equilibrium.

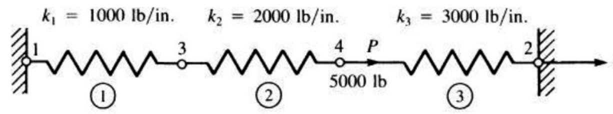

Figure 5: Spring assemblage in axial loading [16]

This results in the product of 4x4 stiffness matrix, [K], and the 4x1 displacement matrix, {U}, which is then equated to the 4x1 load matrix, {F}. This is shown below:

The second step involves applying the boundary

$$\begin{bmatrix} 1000 & 0 & -1000 & 0 \\ 0 & 3000 & 0 & -3000 \\ -1000 & 0 & 3000 & -2000 \\ 0 & -3000 & -2000 & 5000 \end{bmatrix} \begin{Bmatrix} u_1 \\ u_2 \\ u_3 \\ u_4 \end{Bmatrix} = \begin{Bmatrix} F_{1x} \\ F_{2x} \\ F_{3x} \\ F_{4x} \end{Bmatrix}$$

conditions (that nodes 1 and 2 are fixed), resulting in a 2x2 reduced stiffness matrix, 2x1 displacement and 2x1 load matrix as shown. Here the two unknowns are the nodal displacements at nodes 3 and 4. Since there is no load applied at node 3, $F_{3x} = 0$. At node 4, axial force in the positive x-direction is applied. So, F_{4x} = 5000 lb. In order to determine the unknown displacement at nodes 3 and 4, the 2x2 K-matrix is inverted and multiplied by the 2x1 load matrix.

{ 3000 −2000 } { 3 } =
{ 3 }
−2000 5000

The final solution to this problem gives u_3 = 0.91-inch and u_4 = 1.37-inch. Usually, the submission requirements of a homework or in-class problem end here without regard to understanding the real world application(s) of such problems. Even if we discuss the real world applications of this problem, such as a trailer hitch to pull heavy loads, or rail car wagons connected to each other, under what circumstances the results obtained make sense, is not usually addressed.

One of the critical real life examples of this problem can be the tow bar of an automobile trailer shown in Figure 6 (Ref. 18) below. Although the tow bar geometry doesn't look like the given three springs in series problem, the students needed to understand that the tow bar is subjected an axial component of load and that the axial stiffness of the connecting members can be computed using simplified formula, AE/L, where A is the area of cross section of each section of the bar, E is Young's modulus of elasticity, and L is some equivalent length of the tow bar. But, does it make sense to have such large deflections at intermediate sections of the bar? If it is rail cars of a train, are the results acceptable? It is to be noted here that (a) the students are not expected to find the real life applications that exactly match either the geometry or the loads specified in the given problem statement, and (b) they do not have to carry out any redesigns – they just have to think of an appropriate application based on the given data, and discuss the implications of safety and societal concerns if any.

For this case, the students included a discussion of failed tow bar of another kind, and the safety concerns

Figure 6: Real life application an axially-loaded tow bar of an automobile [18]

of poor designs, and their impact on the society (traffic delays due to an accident, etc.). They can propose new designs if needed as a part of mini or final project for this or for another course by modeling a particular tow bar and performing parametric studies to come up with better designs. Figures 7 and 8 show the example of a failed hitch and the societal impact such failures can cause if it happens on a highway.

Assessment tools

Simple feedback in the form of learning outcomes that the student reports contain, and informal surveys have been conducted several times during the term

Figure 7: Failure of a hitch due to poor design or overloading conditions

Figure 8: Possible safety and societal impact leading to accident of poor designs

using Likert's scale. Overall, 70% to 80% of the responses indicate that including a discussion of real life applications of in-class and homework problems:

- enhanced learning experiences of the particular course topics covered in those problems
- understood better the real life applications of the in-class and homework problems

- understood the magnitude of the results obtained better to see if they make sense
- understood the implication of producing better and safe designs
- understood the implication of unsafe designs on the society in one way or the other

Few students felt it too much of work to expect real life examples of every homework, while others felt it unnecessary as a part of the course work. Many students indicated that many instructors in other course (except for capstone courses) did not require inclusion of real life applications of homework problems. This may be because, many courses give digital assignments without regard to having them realize the real life engineering applications.

Appendix A gives a sample student's homework report which is based on the use of direct stiffness finite element procedure for solving thermal stress problems. The assigned problem is open-ended requiring some iterative steps in the procedure. The student has some co-op experience in the use of thermal sensors for automotive applications.

Conclusions and scope for further work

In this paper, the teaching and learning (T&L) experiences of requiring the students to include real life engineering applications of several in-class and homework problems is discussed. Further, the impact of poor designs on safety and society at large has also been discussed through sample examples in three different courses. The author collected several students works that are "Very appropriate" to the given problem or mini project statements. Several simplified models of real life examples have been attempted for the final project in the machine design and finite element analysis classes. Overall feedback from the students indicates a fair level of acceptance of the ideas presented in this paper. Surveys and learning outcomes from the student-written reports are also positive while few students felt it challenging or unnecessary requirement for homework. Some students liked the digital assignments that require parametric studies only without much regard to understanding the practical applications of such problems or projects.

Formal assessment of the data can be done and the practice of requiring an inclusion of real life engineering applications in several homework problems, mini and final projects will be continued in future.

Acknowledgements

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[18] https://www.google.co.in/search?q= tow+bar+for+a+car&espv=2&source=lnms&tbm=isch&sa=X &ved=0ahUKEwjP6auHh-DSAhVKsY8KHTh VCFgQ_AUIBigB&biw=1348&bih=609

[19] https://www.google.co.in/search?q=failed+tow+bar+for+a+car&espv=2&source=lnms&tbm=isc h&sa=X&ved=0ahUKEwjJpZm9h-DSAhVIOo8KHadBCg0Q_AUIBigB&biw=1348&bih=609#imgrc=h6WBAS8RgGao0M:

Appendix – A

Finite Element Analysis: Summer 2016

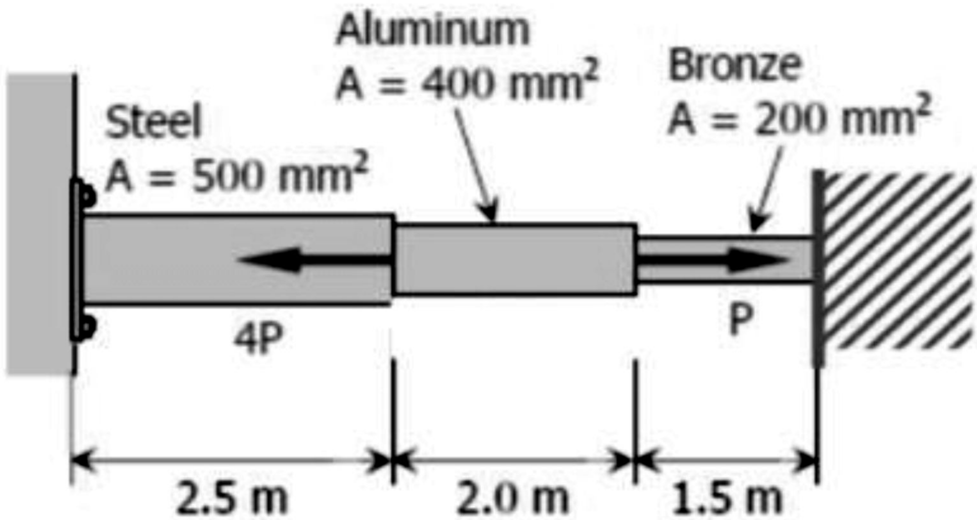
Homework 5: Thermal Stress
Completed by
Student 'a' (edited by the author slightly)

Problem statement (Ref: Chapter 15: Thermal Stresses of Logan book [15])

An aluminum rod is rigidly attached between a steel rod and a bronze rod as shown in the figure. Both ends are fixed. Two axial loads are applied at the middle sections as shown. Find the maximum value of P that will not exceed a stress in steel portion of 150 MPa, in aluminum portion of 90 MPa, or in bronze portion of 100 MPa. A hint was given to the students solving this problem.

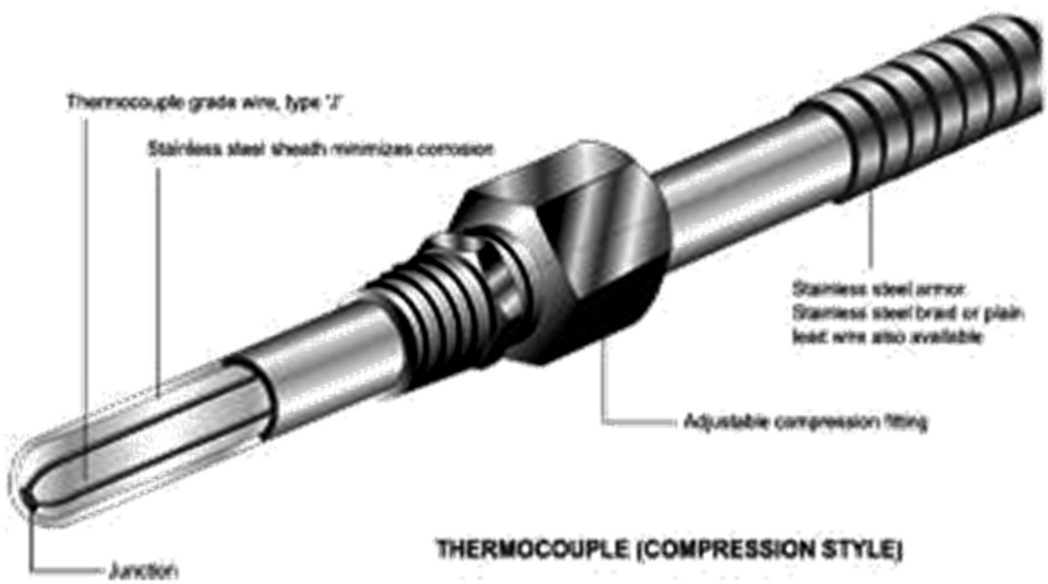
Hint: Assume a value for P and perform iterations to satisfy the given stress conditions.

Student wrote MatLab code for obtaining the solution to this problem (not included here)



Real life application:

This homework problem is an example of thermocouples or multi material systems. Thermometrics Corporation is one of the companies who manufacture such probes which have at least two junctions: the measurement junction and a reference junction. Typically, thermocouples and thermistors are found in a vehicle exhaust environment. The resistance will decrease with increasing temperature. Thermistors offer a high sensitivity over a smaller range in temperature than either thermocouples. Although the given textbook problem has both ends fixed, the thermocouple shown below has one end free and so is not an exact replica of the given problem.



Source : http://www.thermometricscorp.com/images/Thermocouples/thermocouple_diagram-1.jpg

Safety issues

Temperature measuring sensors are critical to measure temperature differences and they have to be designed carefully so that the measurements are correct. Measuring wrong temperatures in the exhaust systems may lead to interpreting combustion temperatures wrongly. This can result in faulty control systems and incomplete combustion.

Societal impact:

Measuring and interpreting wrong temperature may eventually result in emission of undesirable gases that slowly pollute the environment causing other side effects (polluted water, reducing plant life, etc.). Also, quality control at the production environment and the company reputation of both the thermocouple company and the exhaust company manufacturers will be affected leading to customers using alternative brands.

Learning outcomes and how they map to given CLOs

This homework provided me an opportunity to learn how to use the direct stiffness method of FEA and MatLab to solve thermal stress problems. Further, I am able to identify real life application of this concept to understand how temperature sensors such as thermocouples and thermistors are designed. Finally, I understood how critical it is to design these sensors for safe operation and for proper measurement of temperature in automotive exhaust systems to avoid pollution of the environment due to incomplete combustion.

The above mentioned learning outcomes map directly to many CLOs provided in the course syllabus, namely,

1. apply the knowledge of Matrix Algebra, Statics, and Solid Mechanics courses to a basic understanding of "What", "Why" and "How" about the Finite Element Method and its engineering applications.
2. model a given physical system ready for analysis by the Finite Element Method.
3. formulate the Finite Element equations for 1-D and 2-D finite element problems.
4. familiarize with the computational tools used for the FEA process.
5. understand the solution process and the solution method used.
6. understand the validation process to correctly interpret the results in a view to make any design changes to a component or a subsystem.
7. understand the risks and limitations of FE solutions and simulations

Author's comments about the student homework:

Although the student made a good attempt to find an application appropriate to the problem and discussed the implications of its safe design, there are other critical examples that some other students gave, such as electromechanical sensors for electrical applications, optoelectric fiber sensors used in medical and other applications, etc.