AC 2008-1350: DESIGN PROJECT DESIGN FOR AN ELEMENTARY STRENGTH OF MATERIALS COURSE

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Abstract

Our goal is to enable deeper learning by undergraduate engineering students via experience with an open-ended design project. In addition to knowledge, comprehension, and application, engineering design requires students to analyze and synthesize. Furthermore, students must practice divergent thinking to explore the entire design space, which is an immensely important skill for developing creative and effective solutions. Learning design via a team-based design project promotes cognitive skills, social skills, management skills, and positive personal traits.

Design and development of an open ended design project is discussed. The team-based project progresses over approximately ten weeks in an elementary strength of materials course. This provides a significant design experience for engineering students that helps bridge the gap between the first-year engineering design course and the capstone design project that engineering students typically do in their senior year. The project requires student teams to: work together, apply standards, create a conceptual design, select appropriate materials, identify applied loading scenarios, perform the design analysis, check design calculations from another team, create design drawings, estimate the cost, and write a design report.

In order to accomplish all this in a course like strength of materials, which is laden with analysis, the project must be well organized and accompanied with web-based tools. This paper discusses design of the design project, course content that is beyond the traditional strength of materials course coverage, and development of web-based tools that make this possible. The web-based tools provide guidance on: the design process with interactive examples, analysis and simulation, materials properties and selection, administering team projects (for instructors), working team projects (for students), as well as environmental, economical, social, and ethical issues.

Introduction

Engineers apply scientific knowledge and mathematics to design things (e.g., products, structures, systems, methods) that benefit mankind. The act of designing a product, device, or system requires analysis and synthesis. The key words above: knowledge, apply, analysis, and synthesis, comprise four of the six levels of Bloom's hierarchical taxonomy of learning[1] in the cognitive domain.[2] Design requires synthesis, which in turn requires analysis, application, comprehension, and knowledge. In addition, and of critical importance, design demands more than simply applying facts correctly; it requires divergent-convergent thinking.[3] Dym et al.[3], provide a historical review of the role of design in the engineering curriculum. Other recent articles on engineering design projects include Moretti et al.[4] on using design problems to assess life-long learning and Smith[5] on how a design course can self regenerate itself to remain current. The present work builds upon the articles of Salamon and Engel[6,7] on design projects in engineering mechanics.

One of the goals of engineering education is to equip students with a strong foundation on which they can build throughout their lifetime. It is commonplace for engineering curricula to provide cornerstone design experience in the first year and capstone design experience in the final year. Between the first and final years much knowledge is acquired and analysis skills are honed, but the amount of exposure to realistic design problems is variable, if not quite limited.[3]

Elementary strength of materials is a core course in the engineering curriculum in which students learn how to analyze deformation, strain, and stress in simple structural members including bars, shafts, beams, and pressure vessels. It is typically taught at the sophomore level in baccalaureate and engineering technology (ET) programs as well as at community colleges. Traditionally the course is analysis based, although design problems of a very limited nature are introduced. Because it applies scientific principles in an analytical framework to physical problems, the course provides the engineering fundamentals necessary to introduce a significant engineering design experience. *Our thesis is that the application of strength of materials principles through problem-based learning by using realistic design problems that are open-ended and require students to synthesize a solution through a design project improves the preparation of engineering and ET students for a lifelong career.*

The success of our thesis hinges upon development and application of an internet design tool to serve as a scaffold for teaching design in a traditionally analysis-laden course practical because no content has been removed from the syllabus. In-class project time is quite limited. The design tool is intended to be used as supplemental material for courses taught at diverse institutions including: major research universities granting bachelors degrees, satellite campuses of a major university that grant associate and technology degrees as well as send students on to the primary campus for bachelors degrees, teaching-focused colleges, and community colleges.

There are three primary overall objectives associated with testing our thesis. All three are listed below for completeness, but this paper only covers the first one.

1. Engage engineering and ET students in realistic design experiences that require structural analysis, materials selection, interpreting design requirements, using standards, and cognitive skills through provision of mechanical design and data retrieval methodologies, interactive design examples, sample projects, and project management for students and faculty via the internet.
2. Attract various faculty to teach application of their science through provision of the wherewithal for students to do design. Our trial application is for the elementary strength of materials course.
3. Assess the effectiveness of the design experiences to better prepare students for careers in engineering where they will be required to routinely perform higher level thinking in the form of synthesis and evaluation to solve open-ended problems that require iterative divergent and convergent thinking. Additionally, we must ensure that the design focus does not hinder students from learning analysis skills.

In this paper we describe the design of an open-ended design project, course content that is beyond the traditional strength of materials course, and the internet tools created to support the project. The project and associated internet tools are targeted for E MCH 213D Strength of Materials with Design, which is currently only offered at the University Park campus of Penn

State. E MCH 213D meets for 50 minutes 3 times a week for 15 weeks. General topics covered include stress, strain, material behavior, axial loading, beam bending and shear, column buckling, torsion, thin-walled pressure vessels, combined loads, and stress transformation. Ongoing efforts will expand this project to an ET curriculum. Once our thesis has been verified, we will commence with nationwide implementation.

Selecting the Design Project Problem

The first project that we have fully developed requires design of playground equipment and serves as an example for future projects. Design of playground equipment involves creativity (geometric configurations, materials selection), data mining (anthropometric data for sizes and weights of people, material properties, library and web search), standards (over 70 related ANSI standards), and specifications (for a target market). The combination of these elements makes it an ideal project for elementary strength of materials students.

If viewed in general terms, the design of the optimal design project has quite a number of constraints. To be realistic, it must be open-ended. This may be the most important feature because most students at this level are accustomed to problems with one unique answer. In order to ensure that they pursue the best candidate solution, teams must apply divergent thinking to expand the design space rather than simply converge upon a unique solution. This requires open minds and is assisted through diverse teams that must make decisions about what candidate designs to pursue.

The project statement should require the students to understand and interpret the design requirements and create their own conceptual design. Fully understanding the physical problem is key to communicating ideas within the team. From that understanding, they can create a model to analyze using the course theory. Conceptual design sketches are critical to this communication. Most textbook homework problems provide the model as a given, so this is an extremely valuable experience in preparation for engineering practice.

Material selection is an integral part of all engineering designs. While material selection is not a topic typically covered in elementary strength of materials courses, material behavior is covered in a reasonable amount of detail. By supplementing knowledge of material behavior in terms of strength, serviceability, and environmental sustainability with a basic material selection technique, the students' comprehension of materials and their behavior and ability to design with them are both enhanced. The project requires teams to select materials based on more than just historical experience and justify their selection.

Analysis of structural designs today employ sophisticated computer programs (e.g., solid modeling for shape, volume, weight and finite element methods), but these are beyond the scope of elementary strength of materials courses. The design project must be compatible with analysis techniques covered in class (e.g., bars, trusses, beams, columns). It is important to realize and emphasize that we do design with the theory at hand and success of it is not restricted, only the precision of the design. To wit, Roman roads and 14th century cathedrals still stand and function and their design did not employ finite elements. Some candidate design projects include playground equipment, ladders, hand carts, lamps, chairs, and wind boards.

Logistically, there must be sufficient time for the students to do the design while the necessary course material is covered in class. This just-in-time instruction enables the project and constrains it to a duration of about 10 weeks out of a 15 week semester. Furthermore, time is needed at the beginning of the semester to form the teams in a rational manner.[6] Randomly formed and self-formed teams have a higher probability of becoming dysfunctional.

Projects should be selected (designed) so that enough tasks (e.g., enough structural components) exist for each team member to make an individual strength of materials-related contribution. General considerations for a design project are that they should be linked to accessible standards to guide students, should be interesting and familiar to students, and should inspire creativity. The use of standards makes the project realistic and provides much needed experience with searching for and then using standards; of course, instructor/librarian guidance toward finding key standards is helpful as is the ANSI website[8]. Selecting something that is interesting motivates students to learn. Selecting something that is familiar to students saves them the time it would take to get familiar with a new product or device, and time is important. Selecting something with vastly different possibilities inspires creativity by allowing for multiple variations.

The Design Project

One project that satisfies the requirements of a design project is a combination gym set. The full project statement is shown in Figure 1. Teams are to design a gym set that includes a horizontal ladder to be used as monkey bars, two vertical ladders, the support structure for a pair of to-fro swings, and any additional support structure necessary to prevent tipping or collapse. Some specifications are given, but in order to not bias the conceptual designs, no picture of the perceived gym set is provided. The design is to adhere to the ASTM F 1487 standard for playground equipment, which is provided by us, but students must research others as a homework problem.

As shown in Figure 1, there are eight project submittals (milestones). Since the organization of the project is critical to its implementation without overloading the students, the instruction sheets for the submittals are provided in the appendix. In addition, each team is instructed to keep all project materials (including brainstorming lists, rough sketches and calculations, meeting notes, lists of action items, etc. as well as all submittal items) in a design portfolio. The portfolio is to have nine sections; one for each submittal and one for everything else. Teams are instructed to address the grader’s comments before the next submittal, and to keep graded work in the portfolio along with newly revised work.

Problem

Design a Combo Gym Set that contains the following elements:

1. A horizontal ladder with rungs to be used as monkey bars,
2. One or more vertical ladders to support the horizontal ladder and to provide access to the horizontal ladder,
3. Support structure for a pair of to-fro swings, hand rings and/or trapeze bar,
4. Additional support members (e.g. diagonal members) sufficient to prevent tipping or collapse of the Gym Set under normal usage.

Specifications

The Gym Set is intended for use as a backyard play set, but should conform with all of the specifications set forth in the ASTM F 1487 standard except the requirement that to-fro swings must not be attached to a composite play structure. The range of users encompassed by the ASTM F 1487 standard is the 5th percentile of 2-year-olds through the 95th percentile of 12-year-old children.

- The footprint of the Gym Set should not exceed 20 ft by 30 ft.
- Safety factors are 1.3 for yield strength of ductile material, 2.0 for ultimate strength of brittle material, and 2.2 for buckling.
- Deflections of horizontal members must not exceed ½ inch under normal full load and ¼ inch for any ladder rung.
- The Gym Set must ship disassembled and be able to be assembled using basic household tools.

Design Objective

The design objective is that the Gym Set be low cost, but not at a loss in appearance. (Costs are to be estimated using nominal retail prices.)

Special Concerns

- Joints made by commercially available connectors must be adequate.
- Safety in general is a major concern. The Gym Set should be stable under normal use.

Design Report

The design will be done in U.S. Customary Units. Follow instructions in “The Design Report Format”.

References

ASTM F 1487 “Standard Consumer Safety Performance Specification for Playground Equipment for Public Use”

Project Submittals

DP1, Conceptual Design – submit dimensioned sketches showing the layout of the gym set; components do NOT need to be sized; identify the components and connections that will be designed – Due Oct. 8
DP2, Material Selection – identify the materials to be used in the design; list the relevant materials properties; provide a rationale for your selections – Due Oct. 19
DP3, Load Specifications – state the load specifications that will be used in the design and provide justification for these values; identify the applicable standards – Due Oct. 29
DP4, Design Analysis – submit the complete design analysis including assumptions, warnings, calculations, and design sketches – Due Nov. 12
DP5, Calculations Check – provide a check of calculations prepared by another team; comment on assumptions, underlying ideas, applicability of formulas used, as well as correctness of sample computations – Due Nov. 16
DP6, Drawings – prepare design drawings of the gym set of the quality necessary for fabrication – Due Dec. 3
DP7, Cost Estimate – estimate the cost of the gym set; document sources of prices – Due Dec. 10
DP8, Design Report – organize and format the submittals DP1-DP7 into a professional quality report – Due Dec. 14
An instruction sheet that will double as a cover sheet will be provided for each submittal.

Figure 1: Combo gym set design project statement

Course Content Alterations

While no major topics have been omitted from the course, several modifications to the schedule and syllabus are necessary for this project. Since torsional analysis is not necessary for the gym set design project, coverage of torsion has been moved to near the end of the semester. On the other hand, buckling is likely to be a design consideration. Thus, buckling is covered immediately after beam deflections. Topics are generally covered in a 'just in time' mode for the design project. There are a couple of class periods that are devoted exclusively to design content, and pertinent design considerations are discussed periodically as the project proceeds. Supplemental homework assignments related to design are given in Figure 2. The project was used in E MCH 213D in the Fall 2007 semester, when 14 students were formed into 4 teams.

1. Develop the conceptual design of a deck structure for a house to meet the following constraints. The house is located in central Pennsylvania. The deck is to be 20' long and 10' wide and supported by the exterior wall of the house. The length dimension is measured along the wall and the width dimension is measured normal to the wall. Since the ground level behind the house drops steeply to a stream below, additional ground support points are impractical. At this point you can assume that the wall is sufficiently strong to carry the additional loads, but this will be verified by another engineer after the deck structure has been designed. Draw sketches of the design concept, identify loading conditions, and suggest materials for each component.
2. Find the standard for consumer safety performance of playground equipment - for children (not infants). Turn in the front page of the standard and describe how you found it.
3. Identify six features of material behavior that should be considered when selecting the best material for a skate board.
4. Look up the height and weight range (5 to 95 percentile) for a 10 year old girl.
5. Use a spreadsheet to create a bill of materials and cost estimate from the design drawings shown below.

Figure 2: Supplemental design homework assignments

Web-Based Tools

The website Design in Strength of Materials (www.esm.psu.edu/courses/emch213d/) is designed to help students and instructors work through the design project. (That's a lot of design!) The website has ten items on its main menu in various stages of completeness: home, how to use this site, design process flowchart, step-by-step procedures, tutorials/instructional resources, project library, links/resources, contact/feedback, instructor notes, and credits. Some of the key features are briefly described below.

When completed, the home page will cycle through images depicting key elements of the design of a skateboard deck: hand sketch of the conceptual design, material selection chart, free body diagram, analysis calculations of strength and serviceability, CAD drawing, cost estimate, and a video clip of the product in use. Figure 3 shows a screen shot of the home page. Our intent is to lure visitors into the site by illustrating the steps involved with an engineered design.

The design process flowchart breaks the design process down into four phases, describing activities and outputs (shown partially in Fig. 4). The sections on problem definition, concept development, detailed design, and communication/implementation are intended to help guide students through the steps of a design project. The outputs are linked to pages in the step-by-step instructions that provide additional information specific to the strength of materials design project. A second flowchart depicting the design process in more general terms is planned.

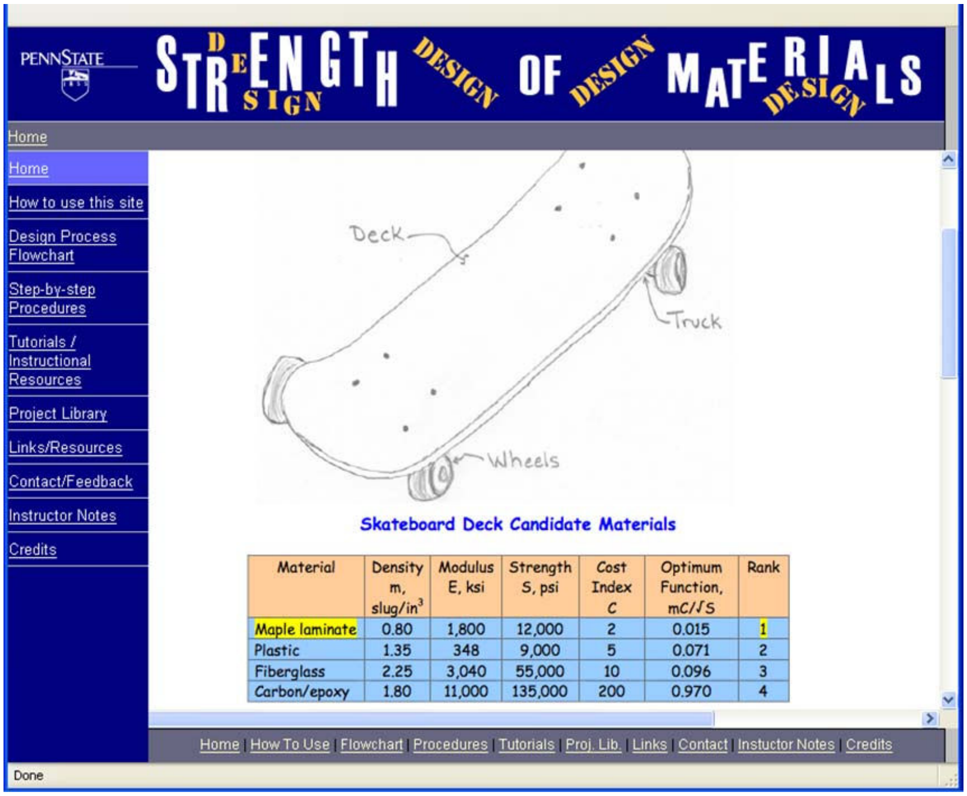

Figure 3: www.esm.psu.edu/courses/emch213d home page

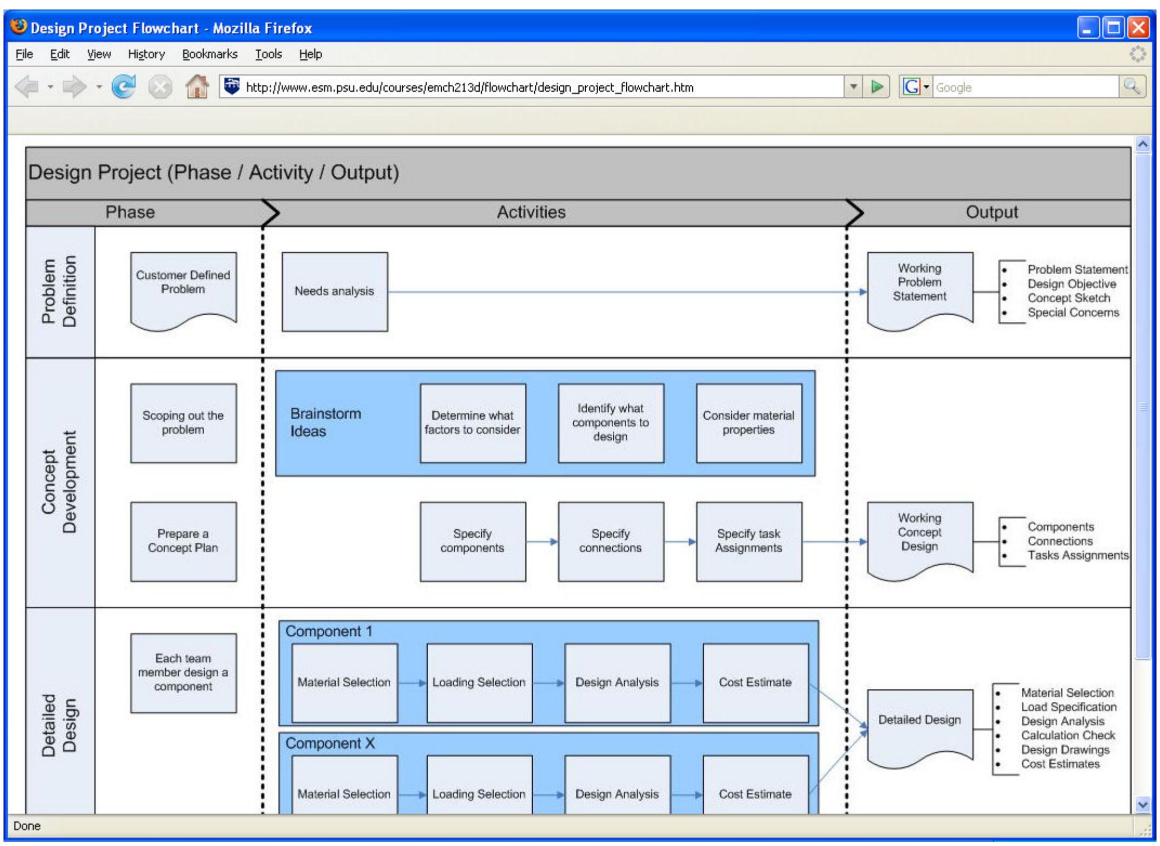

Figure 4: Design process flowchart.

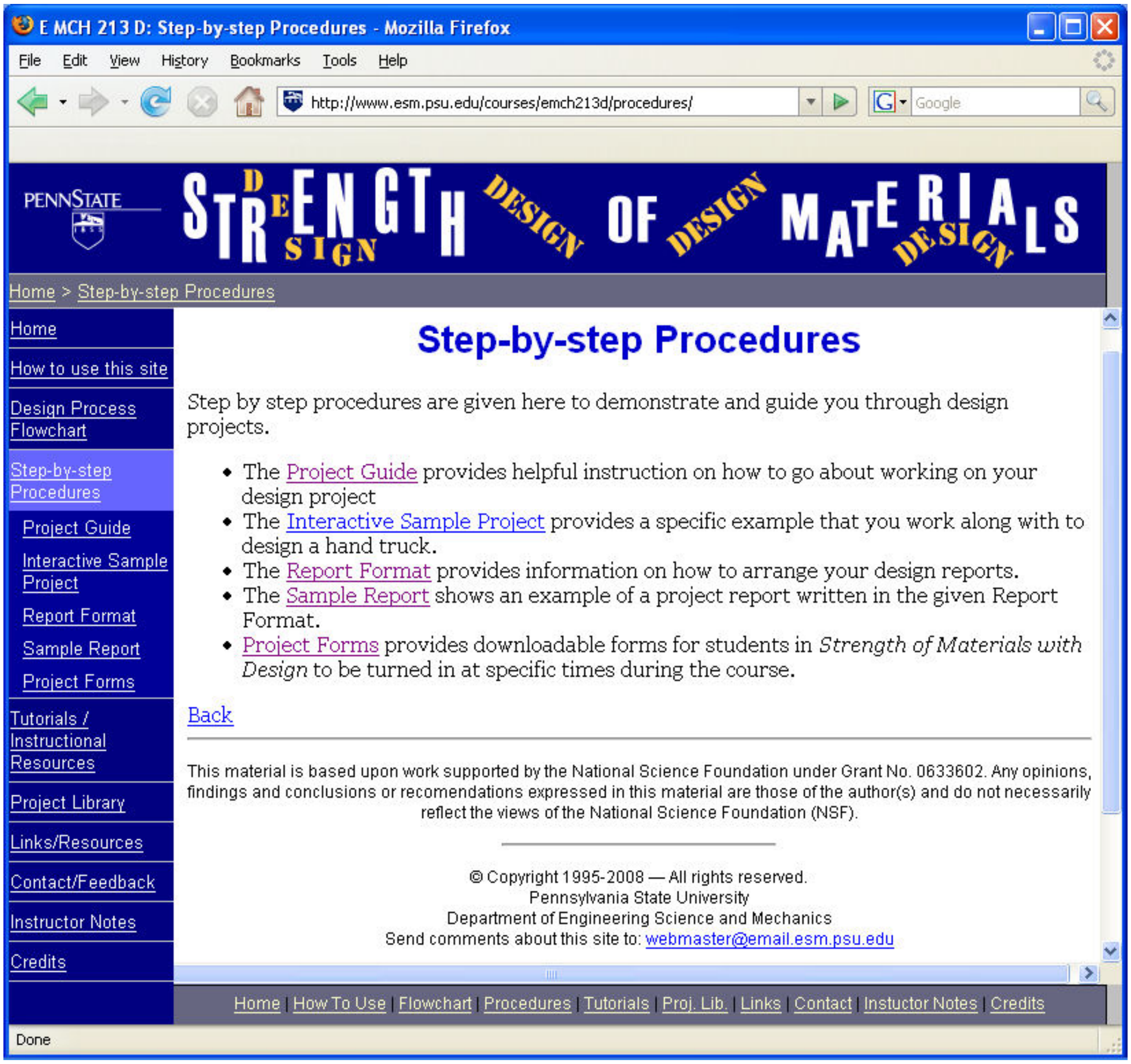

Figure 5: Step-by-step procedures menu.

The step-by-step procedures guide students through the steps in a hand truck design project as an example. There are five topics: project guide, interactive sample project, report format, sample report, and project forms (see Fig. 5). The project guide walks students through the procedures for designing a hand truck. The interactive sample project gives students a chance to actively design a hand truck by making decisions, setting dimensions, and doing calculations. The report format is provided along with how reports are evaluated. A report submitted in a previous semester is available. Finally, the project submittal forms can be downloaded.

Tutorials/instructional resources include design notes (in PDF format), a materials selection tutorial, nine animations for strength of materials principles, and links to analysis learning tools available elsewhere on the internet. These resources are intended to supplement and enrich classroom learning through visualization and additional viewpoints.

Closure

The design of a combination gym set design project for an elementary strength of materials course has been presented. A website is being created to facilitate the team project in an analysis laden course. The first trial of the project was fall 2007. The project and website will be tested and assessed spring 2008 and then extended to the companion engineering technology course. We look forward to sharing those results.

Acknowledgments

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Biographical Information

CLIFF J. LISSENDEN, Ph.D. (University of Virginia, 1993) is an associate professor of Engineering Science and Mechanics at Penn State. In addition to teaching engineering mechanics courses ranging from statics to plasticity theory, he researches structural health monitoring for aerospace, mechanical equipment, and civil infrastructure applications. He is a member of ASEE, SES, ASME, ASCE, ASM, and Sigma Xi.

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Design Project Submittal 1

Attach a neatly hand drawn concept sketch (3D isometric) of your design. Identify all of the components on the sketch with a unique name or number. Include preliminary layout dimensions. Also show preliminary sketches of connections.

Each team member is responsible for leading the design of one primary component and one connection. If your design requires more primary members than team members, then not all members need to be designed. In this case, include a warning in your design report indicating that member X was not designed. Likewise for connections.

Complete the distribution of effort tables below.

Component ID	***Lead Designer***	***Assistant Designer***

Connection ID	***Lead Designer***	***Assistant Designer***

General Task Assignments:

Task	***Leader***	***Assistant***	***Due***
Project Drawings			
Bill of Materials & Cost Estimate			
Methods			
Assumptions & Warnings			
References			
Data Sections			
Calculations Section			
Response to Peer Review			
Peer Review of Other Team			
Design Report Assembly			

All team members will contribute to each task.

The concept sketch should be complete and dated. Its purpose is to guide the design before the drawings are completed and it serves as a simplified sketch for all team members to refer to. Use it to assign tasks, as a reference to parts and their names in forming models and doing the corresponding analyses. For a consistent, organized design process, every team member should have a copy. Components need not be detailed nor presented as finished, but all of them should appear and be called out. The concept sketch may change as the design progresses, in which case revisions must be supplied to all team members. This is the reason for dating the concept sketch. Note that a current concept sketch is part of each submittal.

Design Project Submittal 2

Attach a neatly hand drawn concept sketch (3D isometric) of your design. Identify all of the components on the sketch with a unique name or number. Include preliminary layout dimensions. Also show preliminary sketches of connections.

In the table below, identify the materials to be used for each component in the design. On a separate sheet, list the relevant materials properties and the source of these data. As a minimum, include elastic properties E and ν and the appropriate strength parameters. Also provide a rationale and calculations (if necessary) for your selections. Low cost is the design objective, but the intangibles include at least: safety, aesthetics, durability, environmental impacts, and recycle-ability. Naturally, how the components are manufactured and assembled will affect the cost and need to be considered.

Component ID	***Complete Material Description***

Design Project Submittal 3

Attach a neatly hand drawn concept sketch (3D isometric) of your design. Identify all of the components on the sketch with a unique name or number. Include preliminary layout dimensions. Also show preliminary sketches of connections.

State the load specifications that will be used for the design and provide justification for these values. Identify the applicable standards. Clearly identify supports and how they are modeled. Draw the FBD of each primary component and connection showing all applied forces and reaction forces. Consider the possibility of there being multiple loading conditions that will necessitate multiple FBDs for a single component.

Design Project Submittal 4

Attach a neatly hand drawn concept sketch (3D isometric) of your design. Identify all of the components on the sketch with a unique name or number. Include preliminary layout dimensions. Also show preliminary sketches of connections.

Submit the complete design analysis including assumptions, warnings, FBDs, and calculations for both strength and servicability. Show that the maximum stress values are below the allowable stress (strength divided by safety factor). Calculations can either be done by hand or with the aid of a computer program. If a spreadsheet program is used, show sample hand computations that demonstrate what the program is doing. There is no need to use a word processor for reporting the calculations. If you develop design equations from standard analysis formulas, show this development one time. Calculations lead the team to decisions regarding member sizing, adequacy, material choice, safety, etc. Both the task leader and the assistant need to approve each decision with their signature.

An outline of the design analysis is:

1. identify the component (name or number), show it in situ (on concept sketch)
2. sketch the model with loads and label it for each loading scenario, show support conditions symbolically
3. draw the FBD
4. analyze each cross section (there may be more than one), give materials and allowables, assumptions and warnings, and references; report new data to team; develop design equations from standard formulas; use and update data tables (materials, loads, etc.)
5. make decision; specify sizes being careful about nominal and actual dimensions; any other conclusions; report to team
6. leader and assistant sign off on each decision
7. repeat steps 3-6 for each loading condition

Design Project Submittal 5

Check the design analysis of another team. Comment on assumptions and warnings, underlying ideas, applicability of formulas used, materials selection and data, adequacy of references, correctness of sample computations, and completeness. Use this sheet for your comments.

Design Project Submittal 6

Prepare professional quality drawings of the design with a CAD program. The detail of these drawings must be sufficient to fabricate and assemble the components. Include a 3D rendering created from the CAD program in addition to the isometric drawings of components showing assembly. Show details to clarify component connections, joints, and as otherwise necessary. Assign a part name or number to each individual element. Any hardware purchased off-the-shelf does not have to be detailed (e.g., bolts, pulleys, chain, wheels), except to show how it fits into the design, but a model number is required.

Before submitting the drawings have a team ***design review meeting*** with all team members present to check the drawings AND make sure that all the components fit together, design specifications and loading conditions have been applied uniformly, etc.

Meeting Date: ___________________

Attendance: _____________________

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Design Project Submittal 7

Prepare a bill of materials with cost estimate using a spreadsheet (e.g., Excel). Reference all sources for unit costs below the table. Each item/part in the bill of materials must be clearly identified on the design drawings, which must be attached to this submittal.

Design Project Submittal 8
Design Report Format
General Requirements

General (10%). A design report should be of high quality (clear, neat, correct grammar and spelling with adequate margins) and follow in order the numbered sections 1-10 below. It should be terse, well illustrated and not crowded. Text should be typed in 12 pt. Times font. Calculations should not be typed; do them with a pencil. Use one side of 8.5 x 11 in paper only.

The report should be assembled in the order of the sections given below, pages numbered and bound by a medium-sized metal binder clip (an inexpensive clamp). **Do not use report covers** and **do not staple** reports. Submit the **original** of the report, not a Xerox copy, on or before the deadline.

This general grade also includes any grievous deductions made on design submittals throughout the semester for incomplete or late work.

Report Organization

Cover sheet. It is recommended that the project assignment sheet(s) be used as a cover. The report must include in order the following ten sections; some sections include subsections.

1. **Project Drawings, Parts List and Bill of Materials (15%).** These summarize and communicate your design and must be sufficient to fabricate the design. Drawings must be roughly to scale and must include (1) a *rendering* of your design, (2) an *isometric assembly* with components 'called-out' and correlated by number or part name with the parts list, (3) *details* to clarify component connections and joints and (4) other *details* as necessary. Use professional conventions. Include all dimensions. Do not draw details of standard 'off-the-shelf' hardware like nuts, bolts, washers, castors, etc., just specify them in the bill of materials and call them out in the drawings. The bill of materials lists (1) structural products and their details (materials, sizes and amounts) necessary to fabricate parts and (2) off-the-shelf hardware. It may include weights and costs. The parts list and bill of materials may be combined.

Table 1: Short Sample of Bill of Materials [with weight and cost added][a]

No.	Part	Quantity		Description	Wt, lbs	Unit Cost, $		Cost, $
1	Leg	8	ft	3" nom. Sch 40 pipe 0.216" wall, wrought steel, seamless	60.60	0.69	lb	41.81
2	Pin	4	ea	0.25" dia. x 2" long 303 stainless steel, cold drawn	0.04	1.09	ea	4.36
3	Bed	1	ea	18" x 24" x 0.032" aluminum 1100 sheet	1.38	2.10	lb	2.90
				Totals	62.02			49.07

Note: Quantity usually includes the total quantity (amount, length, etc.) of product used in the entire design. For item No. or Part names in call-outs, length for each is determined from the drawing, not the total value given here. Also note that Sch 40 means item 1 is pipe, not tube, but you may include the word pipe. Weight is the total for the quantity specified. Costs given here are examples and may be inaccurate.

2. **Methods (15%).** This section summarizes in narrative form your design process: your plan or strategy, approach to solving problems or overcoming obstacles, considerations to achieve function as well as form, technical research done, engineering methods used, and in particular, creative ideas and significant ideas discarded. It addresses key design issues such as safety, standards, material selection, and environmental impact. Keep it less than a page and tie it to other sections, Section 1 in particular.

3. **Assumptions (5% w/ Warnings).** This section is a numbered list of assumptions necessary to enable the design. Justify each one. Cite them where used by number. Assumptions raise warning flags and should be used sparingly and only when absolutely necessary for the design to proceed. AN ASSUMPTION IS ONLY

NECESSARY IF THE DESIGN CANNOT PROCEED WITHOUT IT. (For guidelines, read the Design Notes section under Tutorials on the website and discuss this subtle issue in class.)

4. **Warnings.** This covers known deficiencies in the design that are beyond the scope of the project. Warnings serve to alert other engineers and management associated with the project, not the consumer, hence restrict them to technical deficiencies. Do NOT use warnings to avoid doing design that you are capable of doing.
5. **References (5%).** This section is a bibliography of paper, internet and human sources. Cite each where used in the body of the report and list its details in this section. Web Example: AlloyTech, Inc. Pipe Size Chart, http://www.suppliersonline.com (viewed 17 Aug 2007). Other examples can be found in your project assignment sheets, in the Introduction section of the Design Notes on the website.
6. **Data sections (10%).** Data sections establish one place to put basic data which is applicable throughout the design report.

   (1) **Materials Data Table.** Displays property and allowable values and their source. Below the table, provide sample calculations for allowable values. Note: Allowables for metals, plastics, wood and concrete follow different treatments, hence require different sample calculations. Assumptions should also be noted here and listed in Section 3.

   (2) **Loads Data.** Present live loads that the structure must bear. If applicable, calculate dynamic load factors. Dead loads do not appear here, but may be included during design.

   (3) **Other data.** Anthropometric data, codes, i.e., snow loads, standards, i.e., trailer hitch tongue and draw loads.
7. **Calculations (30%).** For each component, show its location within the structure and consider possible loading scenarios. Construct a *Model* for each loading scenario. For each model, draw a *Free-Body Diagram* and do *Analysis*. Then make a *Decision*. Two team members must sign off for each *Decision*. The *Model* displays either the component removed from the structure or the structure itself, with boundary supports. *Free-Body Diagrams* must be drawn even in simple circumstances. *Analysis* is used to determine dimensions or check critical stresses and deformations. The *Decision* sets final nominal dimensions and other conclusions; if it is not obvious, give reasons for it. Title each calculation set by *Component Name*. Sets of calculations should follow a logical sequence. Avoid over-design. Seek a "tight" design near the feasibility limit. Design formulas transformed from conventional analysis formulas should be developed; spreadsheet analysis should be clearly described and a sample hand calculation shown.
8. **Peer Reviews (5%).** The peer review of your design that was done by another team must be included in the design report. Also include the peer review that your team did for another team. Only the latter peer review will be graded.
9. **Response to Peer Review (5%).** This is your response to the peer review of your design. It outlines suggested revisions you accepted and gives reasons why you rejected the others. Do NOT accept flawed suggestions, but consider all thoughtfully.
10. **Appendix.** If you believe you have information important enough to append, place it after the Response Section (Section 9). Keep it brief or exclude it. You do not get credit for this section, but it may be a convenient way to establish a fact or support an argument in the graded sections of the report.

Report grading

Report grading may vary slightly from section to section from the percent values given above. However, in addition to a general quality grade, one should expect point subtractions for low quality work and errors, and additions for exceptional quality work and creativity.

Grading of calculations. Most instructors will not grade all calculations. Rather, one or more components will be selected for grading. Students may suggest two components which received exceptional effort for grading and the instructor may select one or both of these plus other components at her/his discretion.

Questions on grading details should be discussed with your instructor.