Student Success Guide

Department of Mechanical Engineering
California Polytechnic State University – San Luis Obispo
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1 Introduction - Welcome to your Senior Project!

What is a Senior Project?

According to the University’s website:

_The senior project is a capstone experience required for all Cal Poly students receiving a baccalaureate degree. It integrates theory and application from across the student's undergraduate educational experiences._

In this three-quarter sequence of courses (ME 428-429-430), you will integrate knowledge and skills you have gained throughout your undergraduate education to design, build, and test hardware that solves an externally supplied problem for a customer. Design is what most engineers do most of the time and is practically synonymous with the verb “to engineer”. It is a process you will learn best by doing! You will be proud of the things you create, but what is of more importance is the understanding you will take away of the process. You will find this design process useful throughout your life.

Senior project will be very different from most other courses you have taken. First, the courses cover three quarters and you will be working with the same team on the same project for the entire time. Your team output (documentation, presentations, hardware, etc.) will be the result of a team effort. Your grade for the courses will be primarily based on these team products; therefore, it is our experience that any project “failures” will be the result of a team failure.

Every quarter, your team will have two weekly lab periods scheduled with your faculty coach/advisor. The basic structure of the ME Senior Project experience is:

**Quarter 1 – ME 428**

During the first week of labs, all potential sponsors will present their design challenges to the class. After viewing the presentations and getting your questions answered, you’ll complete a project survey to indicate your level of interest in the different design challenges. The teaching team will use this information to form teams and assign labs. If your project ends up in a different lab section than the one you registered for, you will need to change your registration. Once on a project team, you’ll spend a couple of weeks getting to know your team and researching the customers, their needs, and the desired outcomes. You’ll use this to determine your project scope and write a _Scope of Work (SOW)_ report for your sponsor. Next, you’ll spend a couple of weeks developing, evaluating, and selecting concept solutions (ideas). You’ll construct a _Concept Prototype_ to demonstrate your selected design and then present your design to your sponsor as a _Preliminary Design Review (PDR)_.

**Quarter 2 – ME 429**

The second quarter starts with an informal _Interim Design Review (IDR)_ in lab, in which you present your design status and receive input from peers about potential issues. Then, you’ll finish defining your design, build a _Structural Prototype_ and present your detailed design to your sponsor in a _Critical Design Review (CDR)_.

**Quarter 3 – ME 430**

The third quarter will focus on building and testing your hardware prototype and completing the remaining documentation. You'll present your design as a _Confirmation Design Review (CDR)_ to the customer and your faculty team. Upon successful completion, you will graduate and receive your degree.
your build status and testing plans in a Manufacturing & Test Review in lab. During this quarter, you’ll also participate in engineering ethics activities.

**Quarter 3 – ME 430**

In the third quarter, you will finish building and assembling your Confirmation Prototype, have it safety checked at a Hardware/Safety Demo in lab, and then test it to see if it meets your project goals. During this quarter, you will also complete the Senior Exam and Senior Survey. The quarter finishes with a Final Design Review (FDR), which includes your FDR Report, Confirmation Prototype and a Project Expo where you’ll share your work with the public.

Throughout the three quarters, your faculty coach/advisor will guide you through the process of designing, building, and testing a solution to a design problem. This success guide will assist you by providing answers to some of your questions. The best way to use it will be to read it! Please let us know if you find errors so we can promptly get them corrected. Good luck as you embark on a journey of learning, discovery, hard work, and hopefully great personal satisfaction for your completed project!

### 1.1 Course Objectives

1. Apply a formal engineering design process to solve an open-ended, externally supplied engineering design problem.
2. Work effectively on an engineering team.
3. Develop, analyze and maintain an engineering project schedule using a Gantt chart and appropriate software.
4. Use Quality Function Deployment (QFD) to evaluate customer requirements.
5. Formally define an engineering problem.
7. Apply creative techniques to generate conceptual design solutions.
8. Apply structured decision schemes to select appropriate engineering concepts in a team environment.
9. Design systems within constraints (strength, size, materials, performance, cyclic loads, etc.).
10. Evaluate potential design solutions through the use of engineering and physical science analysis techniques and tools.
11. Apply current industrial design practice and techniques such as DFX, FMEA and/or TQM to engineering design problems.
12. Construct and test prototype designs.
14. Communicate and present engineering design project results orally, graphically, and in writing.
15. Discuss and take a stand on open-ended topics involving engineering ethics and product liability.
16. Discuss engineering professionalism and its responsibility to society.
17. Understand the codes of ethics and their implications in engineering practice.

### 1.2 Grading and Assessment

All students, regardless of lab section, will be evaluated based on a common set of deliverables (things you turn in). See chapter 2, Deliverables, for details. These deliverables will be graded by your lab instructor. Reports, presentations, and hardware are the responsibility of the team and will be assigned a single grade shared by all team members. Your faculty coach/advisor can modify this if he or she feels any members are performing less work than others! Other sources of assessment are provided by faculty members who may attend presentations, peer review by fellow students, and input from the project sponsors. In addition,
there will be some individual activities (e.g. logbook, ethics memo, senior exam) throughout the courses. Consult the course syllabus and your faculty coach/advisor for details.

**Late projects are unacceptable.** If there are unforeseen circumstances in which students cannot complete the project on time, a binding contract will be drawn up for the delayed team indicating specific completion milestones and dates. Failure to fulfill this contract will result in a failing grade and the requirement that students enroll in the next section of ME 428 with a new project and a new team. This may delay graduation by up to a full year.

### 1.3 Student, Faculty, and Sponsor Roles

The student design team is responsible for completing all tasks required to produce a final product and report in a professional manner. This is **YOUR** project. The project sponsor, faculty coach/advisor, and course organizer are available to provide technical and management assistance and to help you keep your project on schedule. Here is a list of responsibilities:

**Student Design Team:**
- Attend all labs and participate in activities
- Manage project (define team roles, schedule and track tasks, establish and maintain budget, etc.)
- Define project scope in a written *Scope of Work (SOW)*
- Use engineering skills to design a product
- Document design progress in a *Design Logbook* (recommended on a daily basis)
- Build a Concept Prototype
- Prepare and present a *Preliminary Design Review (PDR)* report and presentation to the sponsor.
- Build a Structural Prototype
- Prepare and present a *Critical Design Review (CDR)* report and presentation to the sponsor.
- Procure materials, fabricate, build, and/or supervise construction of Confirmation Prototype
- Establish a test plan, procure diagnostic equipment, and perform testing
- Complete Senior Exam
- Complete Senior Survey
- Present confirmation prototype and poster at *Project Expo*
- Document entire process in a *Final Design Review (FDR) Report*
- Meet additional intermediate course requirements outlined on syllabus
- Complete all required forms for purchasing and traveling
- Interact with faculty coach/advisor (required twice each week)
- Interface regularly with sponsor (recommended weekly)

**Faculty Coach/Advisor (Lab Instructor):**
- Work with team to define an appropriate project scope
- Coordinate lab activities and presentations
- Mentor team about:
  - Team development (roles, responsibilities, and handling conflicts)
  - Design process & project management (planning, scheduling, tracking)
  - Resources for technical issues
  - Resources for fabrication and testing
- Assist with sponsor-team interactions
- Evaluate all team assignments and assign course grades
**Sponsor:**
- Provide initial design challenge and present to students and faculty
- Be accessible to provide technical assistance and data
- Identify proprietary information to ensure company protection (if applicable)
- Critically review *Scope of Work* to ensure appropriate scope
- Mentor team on customer issues
- Mentor team on resources for fabrication and testing
- Provide funds for building confirmation prototype
- Evaluate team progress at *Preliminary* and *Critical Design Reviews*
- Evaluate team product at *Project Expo* and in *Final Design Review Report*
- Take possession of confirmation prototype at *Project Expo*

**Course Organizer:**
- Collect projects from sponsors and review initial project scope
- Facilitate and coordinate senior design experience
- Arrange *Project Expo* and poster printing
- Work with ABET coordinator to administrate *Senior Exam* and *Senior Survey*

1.4 **Travel Policies and Required Forms:**
By its nature, Senior Design Project typically involves some travel to visit your sponsor or interact with end users. Teams will be given a travel budget that cannot be exceeded for the three quarters and are responsible for maintaining that budget. When possible, you should arrange a meeting at your sponsor’s site during the second or third week of the first quarter. It is essential for you to understand your customer’s requirements. Seeing their needs first-hand is the most efficient way to do this. Preliminary and Critical Design Review presentations in the first and second quarter can be conducted in person or by teleconference, as agreed with your sponsor.

All information concerning travel is available at this website:

[https://me.calpoly.edu/projects/administrative-tools-current-senior-project-students/](https://me.calpoly.edu/projects/administrative-tools-current-senior-project-students/).

NOTE: If International Travel is part of your Senior Project, a supplementary set of forms is necessary and must be completed over a month before intended travel. See the website for instructions.

1.5 **Purchasing and Reimbursements**
During ME 429 you or your sponsor will need to procure parts and materials for your confirmation prototype. All purchases should be discussed and approved by your faculty coach/advisor BEFORE any purchases are made. The preferred method of procurement is to have your sponsor purchase materials for your team and have them drop-shipped (sent directly from the source) to Cal Poly. For some projects, you will need to purchase materials yourself and be reimbursed. How you are reimbursed will depend upon the project. There are three basic methods of materials procurement:

1. **SPONSOR PURCHASES YOUR MATERIALS (PREFERRED)** - Your project sponsor purchases the materials for your team and ships them to Cal Poly at the address below.
2. **YOU PURCHASE YOUR MATERIALS** - Pay for items yourself (with prior faculty coach approval) and submit original receipts for reimbursement. The reimbursement may be from Cal Poly or from your sponsor, depending on the project.

3. **CAL POLY PURCHASES YOUR MATERIALS** – If you have large purchases (>\$150), you may submit a request for the material to be purchased using the Cal Poly ProCard. If you choose to use this method of purchasing, a VISA ProCard Preauthorization form will need to be filled out for each intended use (see Figure 1 for an example). **You must present your ledger or project cost accounting balance to demonstrate funding is available before ordering materials. Your faculty coach/advisor’s signature will be required.**

For delivery of all equipment and components, use this address:

Your Name (your cell phone & e-mail address)
c/o Cal Poly Mustang ‘60 Machine Shop
1 Grand Avenue
San Luis Obispo, CA 93407

Make sure you use the correct zip code!

**Important!** All purchases must be shipped to Cal Poly – **not to your home.**

**Purchasing Restrictions**
(We don’t anticipate any senior project needing these!):

- Any purchase from a single vendor over \$3,500 (tax and shipping included) must be processed as a purchase order. A formal quote will be required from the vendor in order to initiate this.
- Any purchase from a single vendor that exceeds \$5,000 (tax and shipping included) will require three formal bids or a *Sole Source Justification* to process a purchase order.

More information about purchasing materials for your senior project can be found at the Senior Project Budget Information and Forms webpage at:

https://me.calpoly.edu/projects/administrative-tools-current-senior-project-students/.

**1.6 Project Materials & Travel Budget**

Whether or not you directly purchase materials for your confirmation prototype, your team must create and maintain a Materials & Travel Budget for your project. This document (a spreadsheet works well – see example on the Senior project Budget Information and Forms webpage) is your means of ensuring (a) you have adequately planned for all project expenses and (b) as you purchase, you are not exceeding your planned amounts.

You should prepare your Budget file early in the first quarter, while you are developing your Scope of Work. At this point, it would consist of line items for any anticipated travel and an overall budget limit (provided by your sponsor) for prototypes and testing. All budget details (prices and sources for all purchased components) should be added to the budget spreadsheet as you finalize the design details during the second quarter. When you travel or make a purchase, track the actual expenses for all items in a
separate column from the planned expenses, so you can easily see how well you are keeping to your budget.

![VISA ProCard Preauthorization Form]

**Figure 1: Example Visa ProCard Pre-Authorization**
1.7 Intellectual Property and Non-Disclosure Agreements

Two types of legal documents are common during the start of a project initiated between different organizations:

1) An Intellectual Property (IP) agreement is used to declare up-front the ownership of any intellectual property (typically patentable ideas) that may be developed during the project.

2) A Non-Disclosure Agreement (NDA) is used to protect any confidential information shared by the parties during the project, or developed in the course of the project.

Important! Do not sign ANY agreement before consulting your faculty coach/advisor.

In order to protect your rights, Cal Poly Grants Development department will need to review any document the sponsor asks you to sign. The sponsors have been made aware of this, but they may forget and ask you to sign an agreement at some point in the project. Give these agreements, without signing, to your faculty coach/advisor for review.

Many sponsors have agreed to use a standard Cal Poly Class Project Sponsorship Agreement. For these projects, you will be asked to sign Cal Poly Project Confidentiality and Intellectual Property Agreement. Your faculty coach/advisor will provide you with a copy to sign. Many of our sponsors (e.g. Cal Poly, Non-Profit, and most Individual sponsors) do not require IP or NDA agreements.

If you sign an agreement, you should comply fully with its terms. It would be highly unprofessional and unethical to violate the terms of an agreement. Our sponsors have been generous enough to open their doors to us, to bring us projects, to support the projects and teams financially and with their time. The last thing we want to do is to have a student or a group of students use information learned in the course to complete a project to the disadvantage of the sponsor in violation of a legal agreement.

1.8 Senior Project Safety

The ASME Code of Ethics’ first Fundamental Canon is:

“Engineers shall hold paramount the safety, health and welfare of the public in the performance of their professional duties. “

In this class you are learning what it means to be a professional engineer, by acting as a professional engineer on your project. It is imperative that you place safety first in all your senior design project work. This means that you will:

- Design a safe product that does not impose any undue hazard to a user.
- Construct your prototypes in a safe manner
- Test your prototypes in a safe manner.

Preventing injuries or property loss during your time in this class and by the products you design is your first priority. Effective injury prevention involves a process of identifying hazards and quantifying risks. Hazards and risks can be defined as:

- A hazard is any unsafe condition where there is the potential for human, property, or environmental damage.
- The risk is the likelihood, probability, or frequency of a hazard materializing during use.
During the process of designing and developing products, you must determine whether hazard potential is being properly assessed. You must ensure that appropriate product safety features are implemented. The primary concern of product designer(s) should be to develop “reasonably safe” products that are reliable and maintainable. A product is considered “reasonably safe” if the potential risks are judged to be acceptable by society. In general, U.S. society deems products as being not reasonably safe through litigation.

Liabilities stemming from the design and product development process are usually based on one or more of the following premises:
- A concealed danger has been created
- Available safety devices have not been incorporated
- Materials are of inadequate strength
- Failure to comply with accepted standards
- Failure to consider foreseeable possible misuses of the product
- Warnings and instructions are inadequate

Designers should make every effort to minimize and control such hazards using:
- Established design safety criteria
- Applicable mandatory and voluntary (proprietary, industrial, and consensus) standards
- State of the art technologies
- Design safety reviews
- Documentation for the decision making process

Like all organizations, Cal Poly has established Safety procedures and guidelines. Since you will be working in different places on campus, it is important that you review the University’s safety guidelines. They are maintained by Cal Poly Environmental Health and Safety (http://afd.calpoly.edu/ehs/) and can be found at:

- Cal Poly Injury and Illness Prevention Program: http://afd.calpoly.edu/ehs/docs/iipp2.pdf

A special note on designs that include large batteries or electric potentials above 50 volts: You are not allowed to work on wiring these components. You should purchase fully enclosed components/systems or work with your sponsor to outsource the design/build of these electric subsystems. If you can touch the terminals, then it can’t be in your design!

Your first order of business in lab for senior project will be to review and sign the Mechanical Engineering Department’s Senior Project Safe Practice Procedures. The purpose is to raise awareness of the importance of following safe procedures in all activities you engage in at Cal Poly.
Your next task will be to “Design for Safety” in whatever system you are developing for your project. Since Product Safety is not easily quantified, you should employ guidelines as you work on your design. A typical set of guidelines (from Dieter and Schmidt) is shown in Figure 3.
At a minimum you should use the following guidelines as you evaluate your design:

1. Recognize and identify the actual or potential hazards, and then design the product so they will not affect its functioning.
2. Thoroughly test prototypes of the product to reveal any hazards overlooked in the initial design.
3. Design the product so it is easier to use safely than unsafely.
4. If field experience turns up a safety problem, determine the root cause and redesign to eliminate the hazard.
5. Realize that humans do foolish things, and allow for it in your design. More product safety problems arise from improper product use than from product defects.
6. There is a close correspondence between good ergonomic design and safe design.
   - Arrange controls such that the operator does not have to move to manipulate them.
   - Make sure fingers cannot be pinched by levers.
   - Avoid sharp edges and corners.
   - Products that require heavy or prolonged use should be designed to avoid cumulative trauma disorders like carpal tunnel.
7. Minimize the use of flammable materials, including packaging
8. Paint and other surface finishing materials should be chosen to comply with EPA and OSHA regulations. For toxicity to the user and when they are burned, recycled and discarded.
9. Think about the need for repair, service, or maintenance. Provide adequate access without pinch or puncture hazards to the repairer.
10. Electrical products should be properly grounded. Provide electrical interlocks so that high-voltage circuits will not be energized unless a guard is in place.

Figure 3: Design for Safety Guidelines (Dieter & Schmidt)

With these guidelines in mind, you will be developing concepts and finalizing the detail design of your solution. Near the end of ME 428 you will have a Preliminary Design Review (PDR) to present your best design concept generated during the first quarter. The PDR should also include a Design Hazard Checklist. This will focus your attention on the most common potential hazards, to evaluate if they are present in your concept. Any boxes checked will require special attention during your detailed design work.

To ensure your final design will result in a safe and robust product, after PDR you will perform a Failure Mode and Effects Analysis (FMEA). This analysis will result in a set of focused analysis steps you can undertake to address any safety hazards in your design.

After completing your detailed design (including changes to address the safety hazards you identified), you’ll prepare an updated Design Hazard Checklist in preparation for a Critical Design Review (CDR). The CDR takes place in the middle of ME 429.

After CDR, you’ll complete a Risk Assessment of your design, which will help you identify the risks involved with testing and operating your design. The Risk Assessment will then assist you in writing safe testing and operation procedures.

The senior project timeline, with critical safety milestones, is laid out below.
Senior Project Safety Timeline

ME 428 (1st quarter)
- Week 2 – Review and sign the Senior Project Safe Practice Procedures (Figure 3)
- Week 8 – Preliminary Design Review report – include a Design Hazard Checklist (Figure 4 & Figure 5).
- Week 9 – Create an FMEA for your concept design.

ME 429 (2nd quarter)
- Weeks 1-5 – Assess and mitigate identified risks while working on the details of your design. Create an updated Design Hazard Checklist.
- Week 6 – Prepare a Risk Assessment for your design. Meet with mechanical and/or electrical technicians to discuss safety risks and plans. Document any recommendations and plans.
- Week #7 – Develop draft Test Plans and an Operators Manual to address all safety hazards identified in your Risk Assessment.
- Weeks #6-10 – Follow machine shop safe practices and procedure while manufacturing parts of your design.

Important: Do NOT work on your senior project hardware at home!

ME 430 (3rd quarter)
- Weeks #1-10 Follow machine shop safe practices and procedures while manufacturing, assembling, and testing your design. Please note:
  - For any project with identified hazards, your hardware MUST be inspected by a qualified electrician or mechanical technician prior to operation. This can occur at the scheduled Hardware/Safety Demo, or earlier by appointment if you build is complete and you are ready to begin testing.
  - Prior to the Design Expo, final hardware with any known hazards must be reviewed by a safety professional who will determine whether it can run at the Expo.
  - Install safety placards/labels at all safety hazards on your confirmation prototype.

Remember that safety is everyone’s responsibility. As an engineer it is your primary ethical duty. Injuries and property damage often occur when you are in a hurry. There is NO reason you should be in such a hurry to design, manufacture, assemble or test your senior project that you increase the risk of injury. Your and others’ safety is more important than the deadlines! Keep in mind that you are not an expert in Product Safety and neither are the teaching staff. If you have any question about hazards and risks, bring them to your faculty coach/advisor’s attention so s/he can help find the right resources to assess the hazard.

Other campus safety resources:
- Cal Poly Injury and Prevention Program: http://afd.calpoly.edu/ehs/docs/iipp2.pdf
- Cal Poly Environmental Health and Safety: http://afd.calpoly.edu/ehs/
- Online Materials Safety Data Sheets: https://m.msdsonline.com/msdsmanagement/ebinder/
DESIGN HAZARD CHECKLIST

Team: ________________________________  Faculty Coach: _______________________

Y  N

☐ ☐ 1. Will any part of the design create hazardous revolving, reciprocating, running, shearing, punching, pressing, squeezing, drawing, cutting, rolling, mixing or similar action, including pinch points and shear points?

☐ ☐ 2. Can any part of the design undergo high accelerations/decelerations?

☐ ☐ 3. Will the system have any large moving masses or large forces?

☐ ☐ 4. Will the system produce a projectile?

☐ ☐ 5. Would it be possible for the system to fall under gravity creating injury?

☐ ☐ 6. Will a user be exposed to overhanging weights as part of the design?

☐ ☐ 7. Will the system have any sharp edges?

☐ ☐ 8. Will any part of the electrical systems not be grounded?

☐ ☐ 9. Will there be any large batteries or electrical voltage in the system above 40 V?

☐ ☐ 10. Will there be any stored energy in the system such as batteries, flywheels, hanging weights or pressurized fluids?

☐ ☐ 11. Will there be any explosive or flammable liquids, gases, or dust fuel as part of the system?

☐ ☐ 12. Will the user of the design be required to exert any abnormal effort or physical posture during the use of the design?

☐ ☐ 13. Will there be any materials known to be hazardous to humans involved in either the design or the manufacturing of the design?

☐ ☐ 14. Can the system generate high levels of noise?

☐ ☐ 15. Will the device/system be exposed to extreme environmental conditions such as fog, humidity, cold, high temperatures, etc?

☐ ☐ 16. Is it possible for the system to be used in an unsafe manner?

☐ ☐ 17. Will there be any other potential hazards not listed above? If yes, please explain on reverse.

For any “Y” responses, add (1) a complete description, (2) a list of corrective actions to be taken, and (3) date to be completed on the reverse side.

Figure 4: Design Hazard Checklist, Page 1
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Figure 5: Design Hazard Checklist, Page 2
2 Deliverables

There is a minimum set of deliverables required of all student teams in Senior Project. These have been designed to help you practice a structured design process while completing your project in a timely and professional manner. Your lab instructor may have further requirements and deliverables as she or he guides you through the process. Note that any additional work is designed to assist you in completing the fixed set of deliverables in the most timely and professional manner and should not be considered “extra” work. This section describes the common deliverables in detail; check with your faculty coach/advisor for additional requirements. The team deliverables include:

ME 428 (First Quarter)
- Letter of Introduction to Sponsor
- Team Contract
- Quality Function Deployment (QFD) House of Quality
- **Scope of Work**
- Concept Models and Concept Prototype
- **Preliminary Design Review (PDR)** Report & Presentation
- Failure Modes and Effects Analysis (FMEA)

ME 429 (Second Quarter)
- Interim Design Review (IDR)
- Structural Prototype
- **Critical Design Review (CDR)** - Report & Presentation
- Risk Assessment
- Ethics Activities
- Manufacturing and Test Review

ME 430 (Third Quarter)
- Project Update Memo
- Hardware/Safety Demo
- **Final Design Review (FDR)** Report & Expo
  - Confirmation Prototype
  - Expo Poster Presentation
  - Final Design Report
- Senior Project Completion Checklist

In addition to these, there are four individual deliverables throughout Senior Design Project:
- Design Logbook (throughout the project)
- Ethics Memo (2nd quarter)
- Senior Exam (3rd quarter)
- Senior Survey (3rd quarter)

See below for detailed information about each of these deliverables.
2.1 Design Logbook (every week, throughout the project)

The purpose of the design notebook is to document your design process. You can’t begin to realize how important this information is until it is missing; then it is too late. For any design project, the final drawings, models or prototypes are only a part of the value of the design. Much of the value also lies in the process used to generate it. For example, if you contracted with somebody to design a new piece of inexpensive outdoor furniture and the final design calls for aluminum instead of plastic, you would want to know why. The answer might be that the price of plastic was too high or maybe the stiffness was too low. This is useful information and adds to the value of the design, because you will now be in a position to switch to plastic if an oil glut results in a decrease in the bulk price of plastics (not likely to happen soon!).

Parts of the design process that need to be documented include:

- Ideas, questions, and notes from group meetings.
- Notes on sponsor meetings and customer interviews.
- Customer needs/requirements.
- Preliminary sketches, doodles, outlines, half-baked ideas and plans for different aspects of the design. Make sure to annotate these to explain them.
- The analysis you performed. Do calculations directly in your logbook.
- A record of the setup and results from any tests that you conducted.
- Evaluation of data. If you used software, explanations of what it does.
- References and notes on relevant literature and research findings—particularly your conclusions concerning articles that you read or discussions with experts in the field.
- The choices you made at each step: what you chose, what you rejected, and why.
- Conversations with associates and vendors, pasted-in catalog or handbook pages, websites, etc…
- Personal thoughts and reflections concerning the project or process.

[Note that this is not normally included in an industrial setting, but it is important from an educational standpoint. One of the objectives of this class is for you to grow personally so that you understand your particular strengths and weaknesses in approaching a team-based design project. Keep in mind that your lab instructor will be reviewing your logbooks so only put notes and observations that you are willing to share.]

2.1.1 Logbook Details

One logbook is required per person. Consult you lab instructor as s/he may modify the suggested guidelines or details that follow.

Use an unlined, bound sketchbook of high quality (heavy) paper with at least 100 letter size pages. You might want to consider having the pages be larger than 8 ½” x 11” so that you can glue/tape in printed pages without having to cut them (please don’t put folded pages in the logbooks). Examples of completed logbooks can be reviewed at the office of the course organizer. Here are some additional logbook specifications:

- **Contact Info:** Put your name, phone number, email, project name, group contact information, and other pertinent information on the inside cover or the first page. This is especially important should you misplace your logbook!
- **Table of Contents:** Leave five pages at the beginning initially blank and fill them in as a table of contents as you make entries.
- **Time Log:** Create a time log for your project work starting at the LAST page of the logbook moving forward. Make an entry there every time you work on the project.
• **Page Numbers / Dates:** Number each page sequentially and date all entries (note that multiple entries/dates on a page are fine).

• **Permanent:** Don’t erase, simply put a line through any item you would like to delete. If you would like the document to act as a legal record, use INK.

• **Chronological:** Do not remove pages and do not skip pages. Do not backfill. If you realize you forgot to put something in, simply note that as you continue forward in the book by chronological entry.

• **Signatures:** Sign your work when making important entries (for a professional consulting engineer, the signed design logbook can become an important piece of legal evidence in patent and product liability disputes). Have important and novel ideas countersigned by someone who understands your design. This will usually be a teammate or your faculty coach/advisor. They should write something like “I have reviewed and understand the concept presented on these pages”.

• **Timing:** You should be making entries in your logbook at least 5 times each week!

• **Entries:** Include the following types of information:
  - Planning, communication and team activities (10-20% of entries)
  - Research, sketching and engineering analysis (65-75% of entries)
  - Personal notes and review of team and/or product performance (10-15% of entries)

Note that in some cases, your lab instructor will allow you to have a Project Binder for printed pages so you don’t need to paste them all into your logbook. If so, you should consider the binder an addendum to your logbook. In other words, anything you add to the binder should be specifically referenced in your logbook.

### 2.1.2 Logbook Assessment

Your logbook is NOT expected to be a polished, edited document (that is what the formal reports are for). But, another engineer should be able to look at your logbook and tell what you did and why. Your logbook is like your project journal or diary. It is an integral part of your project and its use as such should be reflected in its pages. It should be MUCH more than a few scribbled notes and a repository for taped-in meeting agendas (in fact, leave out the meeting agendas). To know what to aim for in your logbook, pose these questions to yourself:

- If my logbook was the ONLY thing used to grade my project work, how would I fare?
- Is everything I did either written down or referenced in the logbook?

Logbooks will be graded based on tracking of project management information, product development, organization, and personal reflection. Be sure to follow the logbook format specifications given above. In the past we have found a pretty good correlation between good notebooks, good designs, good end of the quarter projects and grades, and functioning hardware that meets the design specifications.

Two common problems we’ve noticed with students’ logbooks:

- Many students think of the logbook as just notes written for the writer. It is not! The logbook is a dialogue about the project, written in a fashion that is understandable by a third party.
  - Annotate, annotate, annotate.
  - Explain, explain, and explain.

  Read the guidelines above occasionally to remind yourself what should be in the logbook.

- Often the context of a calculation or a sketch is missing. Why was the calculation or sketch done? What was concluded from it? Ask these questions upon making every entry: Is what I have written understandable by a third party not involved in the project? Is the context clear (what the
entry concerns, why it is even in the logbook)? Is the reason I am making a calculation or sketch made clear in an annotation? Is what I have concluded from the sketch or calculation stated clearly?

2.2 Letter of Introduction to Sponsor (1st quarter)

As soon as your team is assigned a project, you need to write a letter of introduction to your sponsor. Before doing this, get together with your team and decide:

- Who will be the main point of contact with the sponsor. All future correspondence will go through this team member. You may wish to generate a team email address as well.
- How you will exchange information with the sponsor and store all your project files? Will you use Dropbox, OneDrive, GoogleDocs, or some other method?

Then, compose an email to your sponsor (with a copy to your faculty coach/advisor), identifying the team working on the project (with names, phone numbers, and email addresses of everyone) and clearly stating who will be the main point of contact. You may want to include pictures and a little about yourselves as well.

In the letter, include a restatement (in your own words) of the problem you believe the sponsor proposed. Also indicate that your initial goals are to study the project requirements and scope as well as perform necessary background research. State that you need to meet or have a teleconference within a week to discuss the detailed scope of the project and specific requirements. For local sponsors you should travel to the sponsor’s site during this week to assess first-hand your sponsor’s needs. You may also want to suggest a weekly meeting time (teleconference, Skype, Google hangout, etc.) with your sponsor.

Remember to correspond in a formal and professional manner when contacting your industry sponsor. Document all correspondence and always remember to copy your faculty coach/advisor. Do not send an email with only an attachment. If you do attach a formal letter, make sure you introduce and sign your email message. Think in terms of “friendly” letters. Dear Ms. Sponsor….Thank you for the opportunity….Sincerely, J. Student.

2.3 Team Contract (1st quarter)

To help ensure your team agrees on the best way to operate, prepare a team contract (or set of bylaws) that defines your team's organizational structure and commits all members to agreed-upon operating procedures. This "contract" should emerge from substantive team discussions and from full member agreement. The team contract must be prepared as a formal agreement signed by all members and referenced regularly in the course of team business.

Your team contract should address each of the following issues:

- **Roles and Responsibilities** - Define roles that will be assigned within the team and the responsibilities of the person in each role. State who is assigned the role and any plans for review or reassignment of roles to achieve team and member goals. Specifically address roles for managing (a) team progress and (b) budget, (c) conducting meetings, (d) documenting team information, and (e) communicating with project stakeholders. Also address issues of back-up for members needing help or encountering unexpected challenges.

- **Team Relationships** - Define relationships that are expected among team members and the methods employed to establish and maintain these supportive relationships. Specifically address your
establishment of an inclusive and supportive climate, gaining strong member commitments to success of all members, and ways in which conflicts will be handled constructively.

- **Joint Achievements** - Define what is expected and methods the team will use to achieve high quality work done together (i.e., when members are working together on the same outcome). Specifically address establishing shared goals, planning and monitoring progress toward team goals, and conducting effective team meetings.

- **Member Contributions** - Define what is expected from team members when conducting work individually. Define how individual work assignments will be made, by whom, and with what definition of expectations. Explain how work quality and timeliness will be monitored and enforced (be specific). As appropriate, describe a process by which the team will allocate credit and/or project assets based on member contributions. Also describe how members will be supported in their efforts to develop skills and abilities needed for the project.

- **Information Management** - Define what is expected from team members regarding the recording and sharing of team information (e.g., ideas, drawings, meeting minutes, work status, problems, and coach/advisor/sponsor communication). Specifically address the ways and frequency of keeping members and outside stakeholders informed. Also define how project information will be recorded and made available to members, but also guarded to protect confidentiality and support patentability.

If you search online for “Team Contract,” you’ll find lots of good examples of how to write yours. When your contract is complete and signed by all members, scan it to a pdf document and save it.

### 2.4 Quality Function Deployment House of Quality (1st quarter)

Quality Function Deployment (QFD) is a process for determining the appropriate specifications for a new design, based on market and customer needs. Done properly, it can be a lengthy process involving customer interviews, benchmarking tests, and supporting analysis. In this course, you will follow an abbreviated form of the QFD process in order to develop a House of Quality chart that explains how you arrived at your target design specifications. See the additional details on the QFD process in the Senior Project Reference Book section.

### 2.5 Senior Project Reports – Overview

During senior project, your team will prepare and submit four major reports:

1. Scope of Work (SOW)
2. Preliminary Design Review (PDR) Report

These reports are cumulative: Sections from previous reports are included (with improvements) in subsequent reports. When preparing each report, read its Success Guide description carefully and be sure to include all of the required contents. DO NOT REMOVE any content from a previous report, unless instructed to do so.

As you prepare your reports, focus on these three principles:

- Completeness – Include everything required with sufficient detail
- Clarity – Make sure it is easy for the reader to understand everything you include
- Brevity – Keep the document as short as possible. Use tables, figures, and lists when appropriate.
In addition, follow these guidelines:

- Think about your audience (sponsor, coach/advisor, others who know nothing about the project).
- Use numbered sections, with subsections (4.3, 5.9.3 . . .), similar to this Success Guide.
- Include short introductory paragraphs at the start of each section.
- Have other students critically review your report before you send it to your sponsor.

The following two subsections list a number of grammar, spelling, and formatting errors we unfortunately often find in students’ technical reports. Please review and use these lists to check your reports before you submit them to your coach/advisor or sponsor.

2.5.1 Common Grammar/Spelling Errors

1. Run-on sentences and improper use of the word “however.” Here’s an example:
   - Incorrect: The testing process was detailed, however we recommend further analysis.
   - Correct: The testing process was detailed; however, we recommend further analysis.
   A semicolon is necessary when “however” is used in this way.

2. Improper or inadequate use of commas. Here are two examples:
   - Incorrect: We placed the sample in the water and we measured the displacement.
   - Correct: We placed the sample in the water, and we measured the displacement.
   Because there are two complete clauses, each containing a subject and verb, the clauses must be separated by a comma. These could also be separate sentences.
   - Incorrect: In the wild, a panda eats, shoots, and leaves.
   - Correct: In the wild, a panda eats shoots and leaves.
   In this case, too many commas are used. The meaning of the sentence is changed by them.

3. Using “there,” “their,” and “they’re” incorrectly. Here’s an example:
   - Incorrect: Each of the students in the group submitted their data.
   - Correct: Each of the students in the group submitted their data.
   The word “their” only applies to the possessive form (needed in this case). Also remember that “they’re” is a contraction of “they are.”

4. Improper capitalization. Here are two examples:
   - Incorrect: The Higher Heating Value is determined using Equation 5.4.
   - Correct: The higher heating value is determined using Equation 5.4.
   The term “higher heating value” is not a proper noun and should not be capitalized.
   - Incorrect: As shown in figure 1, the function shows a linear dependence with time.
   - Correct: As shown in Figure 1, the function shows a linear dependence with time.
   “Figure 1” is the name of a figure, and should be treated as a proper noun.

5. Using “its” and “it’s” incorrectly. Here’s an example:
   - Incorrect: We put the item on the scale and measured its mass.
   - Correct: We put the item on the scale and measured its mass.
   The word “its” is a possessive article. The word “it’s” is a contraction of “it is.”

6. Incorrect use of “which” and “that.” Here are two examples:
   - Incorrect: I do not like grammar which is incorrect.
   - Correct: I do not like grammar that is incorrect.
   “That” is used to provide essential clarification to a sentence. If we left out “that is incorrect,” the sentence would have a different meaning.
• **Incorrect**: He does not like grammar that is incorrect that is fine by me.
• **Correct**: He does not like grammar that is incorrect, which is fine by me.

“Which” is used to add a related, but not essential, phrase to a sentence. “Which” is always separated by a comma from the rest of the sentence.

7. Mixed or incorrect tense. Here’s an example:
• **Incorrect**: First, we measured the temperature, then we record the time.
• **Correct 1**: First, we measured the temperature, then we recorded the time.
• **Correct 2**: First, we measure the temperature, then we record the time.

Be careful with your use of verb tenses. In general, don’t mix past and present tense in a single report section. If the section refers to things you did in the past, then write it in past tense. If it refers to current activities, then present tense is appropriate.

8. Incorrect spelling. Here’s an example:
• **Incorrect**: Chosing the best work for a sentance is hard wok.
• **Correct**: Choosing the best word for a sentence is hard work.

Misspelled words really make a report look unprofessional! Don’t just rely on a spell-checker. Software just checks to see if a word exists in a common language dictionary; it does not know whether that word is the one you intended to use.

### 2.5.2 Common Formatting Errors

1. Missing citations. Whenever you include a figure, data, or text that your team did not create, you need to credit the source. This is important because it shows respect for your sources, and also highlights your diligent research. The easiest way to include citations is to place the reference number in brackets ([5]) after the fact or idea in the text, or in the figure or table caption.

2. Improper or incomplete formatting of Works Cited (or References or Bibliography).
   - **Incorrect**: 1. Make Space, http://ka3qg8vr6t.search.serialssolutions.com/?V=1.0&amp;L=KA3QG8VR6T&amp;S=JC&amp;C=TC0000591745&amp;T=marc&amp;tab=BOOKS.

Choose one of the four styles (APA, MLA, Chicago, or AMA) at the Purdue OWL (Online Writing Lab - [https://owl.english.purdue.edu/owl/](https://owl.english.purdue.edu/owl/)) and use it for all of your citations (be consistent). Note that if you use numbers to cite works (e.g. [10]), list your sources in the order you cite them in the text.

3. Improper placement of figure and table captions. Captions for tables are placed above the table. Captions for figures are placed below the figure. Make sure each caption is on the same page as its table or figure!

4. Figures, tables, or appendices out of order. Figures, tables, and appendices should all appear in the order they are mentioned in the text. So, Appendix A is the first appendix that you mention in the text. Reference (or Work Cited) 1 is the first external source you cite in the text.

5. Tables wrap over multiple pages. Tables should be situated so that all rows fit on the same page. If there are too many rows to do this, then the table should be split into separate tables.

6. Figures, tables, references, or appendices not mentioned in the text. Here’s an example:
   - **Incorrect**: The results are shown in the table below.
   - **Correct**: The results are shown in Table 5.
Every figure, table, reference, or appendix should be specifically reference by the text that it supports. If you can’t refer to something in the text, then it shouldn’t be in your document.

7. Hanging titles. Section titles should be immediately followed by regular text. Never put a title at the bottom of a page or a subsection heading directly below a section heading. In the latter case, include at least a sentence overview of the full section before entering a subsection.

8. Unnecessary blank space in the text. Microsoft Word will keep imbedded figures from wrapping over a page break. However, it does this by creating blank space at the bottom of a page. After you are done with your text edits, move your text and figures around to make sure that there are no large blank spaces.

9. Incorrect page numbering. Report page numbers should begin with -1- on the first page of the Introduction and end on the last page of References. Don’t put a page number on your cover page. Your Abstract, Table of Contents, List of Figures, and List of Tables pages should be numbered using lower case Roman numerals (i, ii, iii...). Your Appendices should each have their own page numbering (A-1, B-5, etc.). You can use section breaks in Microsoft Word to create separate regions for page numbering.

2.6 Scope of Work (SOW) (1st quarter)

The Scope of Work is one of the most important documents that an engineer has to prepare – whether you work in government, industry or academia; and whether you are a designer, researcher, or production engineer. The Scope of Work will also be the start of your formal documentation for your project. The Scope of Work will grow into a Preliminary Design Report, a complete Critical Design Report, and then eventually into a Final Design Report.

The Scope of Work is not written to a general audience, but to a specific person (e.g. a client) or to a small group (e.g. a board of directors or a review committee) who have a problem that you believe you can solve. The purpose of the document is to convince that person or group (your sponsor), that:

• You clearly understand what the problem is. This includes defining the scope of your project.
• You have studied the background, related literature and similar hardware, or problems
• You have performed initial analysis to define the problem
• You have a process that you will follow to effectively solve the problem.
• You have the necessary resources and time to complete the tasks.

The Scope of Work must be professional. Statements must be supported; ideas must be defined clearly so that the reader can judge for himself or herself their merits. Above all, avoid self-praise, empty promises, and zero-information statements. The most important sections are the Background and Objectives. Once agreed upon by the sponsor, the specifications included in the Objectives section will become a contract that you are agreeing to fulfill. The SOW should follow the outline in Figure 6.
Figure 6: Scope of Work (SOW) Contents

Each section is described in more detail below:

- The **Title Page** shows the project title, sponsor name, and names and email addresses of the persons preparing the Scope of Work. See section 2.20 - Final Design Review (FDR) for an example.

- The **Abstract** (or Executive Summary) gives an overview of the work presented in the document. An abstract should be one paragraph that briefly describes (a) what was done, (b) what was found, and (c) why it matters. An Executive Summary is similar, but can be up to a page in length and includes more details. See [https://www.wikihow.com/Write-an-Engineering-Abstract](https://www.wikihow.com/Write-an-Engineering-Abstract).

1) The **Introduction** tells the reader what the project is about, who the stakeholders are, and the goals of this report. It should also briefly describe what is covered in each section of the report.

2) The **Background** presents the results you found during your design research (customer/need, product, and technical). It serves as the repository of information about your project, shows your diligence in trying to understand the design challenge, documents alternative solution types (so you don’t have to ‘re-invent the wheel’), and indicates how big of a technical challenge you are undertaking. The reader should be able to read this section and know everything that is important about your design challenge. The Background section will be the longest section in your SOW, so keep your text descriptions concise (use lots of tables, figures, and lists). Be sure to include:
   - Summaries of customer observations, meetings, and interviews
   - Discussion (or table) of existing designs (at least five current or similar products)
   - Table of patent search results (at least five related patents)
   - Summary of the relevant technical literature (at least five engineering journal citations)
   - List of applicable industry codes, standards, and regulations

3) The **Objectives** section establishes the goals, evaluation criteria, and deliverables for the project. It is important to be completely clear about these things when a project begins. All too often, time and resources are wasted designing the wrong system or component because it is poorly specified. This section should include:
   - Problem statement
   - Boundary diagram
   - Summary of your customer wants & needs
   - Brief description of the QFD process (reference House of Quality in Appendix)
   - Engineering Specifications Table, with explanation of terms (see below)
The Engineering Specifications Table (use the format shown in Table 1) documents the evaluation criteria for your project. It is derived from your QFD House of Quality:

- Descriptive title for each specification comes from the HOW section of QFD.
- Target value for each specification comes from the HOW MUCH section of QFD.
- Tolerance is the acceptable variation from the target (min, max, or +/- tolerance).
- Risk is how challenging you think it will be to meet each specification.
- Compliance is the way that you will determine whether your design meets each specification (by Test, Analysis, Inspection, or Similarity to an existing product).

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<th>Specification Description</th>
<th>Requirement or Target (units)</th>
<th>Tolerance</th>
<th>Risk</th>
<th>Compliance</th>
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<td>Max</td>
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</table>

4) The Project Management section shows that you have a process and the resources to complete this design challenge. It should include:

- Description of the overall design process you expect to follow in solving the problem
- Table of key deliverables and the project timeline (reference Gantt chart in Appendix)
- Any unique techniques (early prototypes, special analyses, etc.) you will use on the project
- Discussion of the next steps in the process.

5) The Conclusion should briefly restate the purpose of the document (to get your sponsor’s agreement on the project scope) and the key results, then highlight the next project deliverable and timing.

- Be sure to include a References or Works Cited section. Use proper MLA or APA style citations for all facts, figures, and tables that you obtained from other sources. Check out Purdue’s Online Writing Lab (https://owl.purdue.edu/owl/purdue_owl.html) for detailed information.

- Add Appendices after your references. Note each Appendix is considered a separate document from your main report, so one should not need to read them to understand the report. Each Appendix should have a descriptive title, explanation of what it contains, its own page numbering system (e.g. A-1, B-5, etc.), and references (if applicable). Every Appendix should be specifically referenced within the body of the report, and appendices should appear in the order they are mentioned in the body of the report. Your SOW should have at least two appendices:
  - QFD House of Quality table
  - Project Gantt chart
A high quality SOW may include additional appendices:
  - Preliminary Analyses
  - Benchmarking Tests
In a commercial SOW, there are often other items, such as the qualifications of the proposer(s), reporting schedule, cost estimates, and various contractual conditions. These are not required for your senior project SOW.

2.7  Concept Models / Concept Prototypes (1st quarter)

Concept Models are very simple, quick to build physical models of key aspects of your design alternatives. They allow you to spend very little time checking out alternatives to see if they are viable. While exploring your design alternatives, take some time to build simple models of some of your concepts. These concept models can be as simple as foam-core builds or Lego assemblies, but should allow you to perform simple tests to determine whether or not your concept could meet your design goals. You will share your Concept Models and explain what you learned from them in an informal presentation in lab.

A Concept Prototype is a more realistic representation of some important aspect of your chosen design. It should be at least partially functional so you can discover more about that function. After settling on a main concept, you should build and test a rough prototype of a critical aspect of your design. Try to use easily modified materials - wood, plastic pipe, bolts, hinges, bike parts, etc. The Concept Prototype should:

- Convince you that this critical part of your design will function as intended
- Help you convey how this critical part works, to your sponsor
- Help you preview the challenges of building a full prototype later

The Concept Prototype is also a great way to get more shop hours so you can earn your Yellow Tag! You’ll present your Concept Prototype as part of your PDR presentation.

2.8  Senior Project Presentations – Overview

During senior project, you will prepare and deliver two formal presentations, in lab and to your sponsor:

1. Preliminary Design Review (PDR) Presentation (section 0)
2. Critical Design Review (CDR) Presentation (section 2.13.2)

In addition, you will present one informal presentation (Interim Design Review) and one poster presentation (Project Expo). As you prepare for these presentations, remember what you learned in your Communications courses. As a refresher, check out [http://www.garrreynolds.com/preso-tips/design/](http://www.garrreynolds.com/preso-tips/design/).

Here are a few general guidelines:

- Preparing your Presentation: Visual Aids (slides)
  - Plan on 2-3 minutes per content slide (not including title slides or closing)
  - Every visual should have a purpose. What should your audience take away from each slide?
  - Keep it visual. Base it on your key figures, but:
    - Figures should be informative, not just decorative.
    - Figures should have legible captions and labels to improve understanding
    - Figures should be in high resolution so they are clear when projected onto a screen.
  - Include tables when needed to provide more information, but:
    - Summarize tables to minimize the text. You don’t need every bit of data!
    - All table text should be large enough to easily read.
    - Highlight table columns or rows when you discuss them.
  - Keep text on slides simple and clear:
    - No more than 5 bullets per slide.
    - No more than 5-7 words per bullet.
Text is large enough to read from the back of the room (nothing smaller than 18 pt.).

- Pay attention to the visual details. For example,
  - Lines are aligned
  - Colors are consistent
  - Text is centered
- Be careful with your choice of background:
  - Ensure that there is sufficient contrast between foreground and background.
  - Use care with dark backgrounds. Test with regular room lighting.
  - Avoid distracting background images. Simple backgrounds are best.
- Limit dynamic transitions or animations.
- Test presentation in the room with its projector to verify that all information is legible.

- Practicing your Presentation
  - Practice stage management. Who will be presenting what, and when?
  - Plan good transitions. Introduce the next speaker and what they will be covering.
  - Decide what you will say. Write it down (at least an outline) so you don’t forget anything. Then practice saying it.
  - The more practice you do, the better your presentation will be.

- During your Presentation
  - Clothing should be appropriate for a business setting (A good description of business casual is at https://www.thebalance.com/business-casual-dress-code-1919379).
  - Don’t wear flip-flops, hats, or sunglasses.
  - Explain the purpose of the presentation and who will be presenting each topic.
  - Don’t look at your slides. Use them only to provide a visual aid for your audience.
  - Don’t read from your slides.
  - Don’t interrupt or contradict each other.

- Ending your Presentation
  - Conclude your presentation with a request for questions and comments.
  - Do not put a big question mark on the last slide. They know they can ask a question! Instead,
    - Use a picture of your chosen design
    - List concerns or questions for your sponsor
    - Include a timeline of the next steps.
  - Plan who will answer each type of question. For example:
    - One person handles technical questions
    - One person handles manufacturing questions
    - One person handles part sourcing/budget questions
  - End strong – restate the presentation’s goals and ask for agreement/approval.

### 2.9 Preliminary Design Review (PDR) (1st quarter)

The goal of your PDR is to obtain your sponsor’s approval to move forward in your chosen design direction. In order to do this, your PDR must document your process, explain your selected design direction, and justify your choices. The PDR consists of three components: A written report, an oral presentation (with visual aids), and a concept prototype (already discussed in section 2.7).

#### 2.9.1 PDR Report

The reports you generate in this class are cumulative: This PDR Report is built on the material in your SOW, with appropriate revisions. For the chapters that are updated from the SOW, please include an introductory paragraph describing any changes made. The main goal of the PDR Report is to document
your selected design direction and support that decision with appropriate evidence. Your PDR Report should follow the outline shown in Figure 7.

<table>
<thead>
<tr>
<th>Figure 7: Preliminary Design Review (PDR) Report Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Title Page – <em>identify this as the Preliminary Design Review (PDR) Report</em>. Include a date</td>
</tr>
<tr>
<td>- Abstract or Executive Summary - <em>updated to reflect that this is the PDR report</em></td>
</tr>
<tr>
<td>- Table of Contents</td>
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<tr>
<td>- List of Figures</td>
</tr>
<tr>
<td>- List of Tables</td>
</tr>
<tr>
<td>- Chapter 1, Introduction - <em>updated based on feedback &amp; new research</em></td>
</tr>
<tr>
<td>- Chapter 2, Background - <em>updated, based on feedback &amp; new information</em></td>
</tr>
<tr>
<td>- Chapter 4, Concept Design – <em>describe your concept design process and its results</em></td>
</tr>
<tr>
<td>- Chapter 5, Project Management – <em>updated process description, especially next steps</em></td>
</tr>
<tr>
<td>- Chapter 6, Conclusions – <em>summarize the document and ask for sponsor agreement</em></td>
</tr>
<tr>
<td>- References (or, Works Cited)</td>
</tr>
<tr>
<td>- Appendices</td>
</tr>
</tbody>
</table>

More information about each chapter is given below:

- **Abstract** (or Executive Summary). Updated from SOW to include the new work completed and advisor/sponsor feedback.

1) **Introduction**. Updated from SOW to include the new chapter and advisor/sponsor feedback.

2) **Background**. Updated from SOW to include any new research and advisor/sponsor feedback.

3) **Objectives**. Updated from SOW to reflect new information and advisor/sponsor feedback.

4) **Concept Design**. This new chapter describes your concept development process and your selected design direction. It is the most important part of the PDR report. Be sure to include:
   - Description of the process you used to develop, evaluate, and select your top concepts.
     - Add ALL ideas your team came up with during ideation in an appendix.
     - Add Pugh matrices for each function in an appendix.
   - Brief descriptions and clear sketches of your top 5-10 concepts.
   - Description of the process you used to select your design direction from these top concepts.
     - Include and discuss your final weighted decision matrix.
   - Detailed description of your **selected concept**, including a labeled solid model isometric view figure and pictures of your concept prototype. Explain how it will function. Include any known geometry, materials, manufacturing processes, etc. Indicate what parts of the concept are still incomplete.
   - Preliminary analyses or tests that show your design will satisfy the specifications. Describe the calculations (e.g. finite difference heat transfer) and results (e.g. safety factors) in the text, with a reference to the full preliminary calculations in an appendix.
   - Discuss of the current risks, challenges, and unknowns (it’s important to know what you don’t know!) with your design. Reference the Design Hazard Checklist (see Figure 4 in section 1.8) in an Appendix.

5) **Project Management**. Updated from your SOW to focus on the activities you plan to complete before CDR, and any advisor/sponsor feedback. Be sure to include:
   - Planned analyses.
o Planned purchases (long-lead parts and structural prototypes).
o Preliminary plans for construction and testing your final design.

6) Conclusion. Updated from your SOW to reflect your new results, next steps, and advisor/sponsor feedback.

- References (Works Cited). Updated from the SOW.
- Appendices. Updated from SOW. Each PDR should include at least the following appendices:
  o QFD House of Quality
  o Idea Lists (all ideas developed during ideation)
  o Decision Matrices (Pugh and Weighted)
  o Preliminary analyses and/or testing details
  o Design Hazard Checklist
  o Gantt Chart

As you prepare your PDR Report, review section 2.5 (Senior Project Reports – Overview).

2.9.2 PDR Presentation

As just described, the PDR report provides all the details of your project work and selected design direction, so the PDR presentation only needs to hit the highlights. As with any professional presentation, you should prepare a concise, clear story about your design, with hidden back-up slides to answer questions if they arise. Plan (and practice!) your presentation to ensure you can present it in 15 minutes or less.

Your presentation should cover the following points:
- Introduction: A brief review of your project’s scope & goals (for a general audience).
- Alternatives: Brief descriptions of the other (~5) top alternative design concepts you considered.
- Design Direction: A more in-depth description, explanation, and justification of your chosen design direction. Include your Concept Prototype. (This topic is the main focus of this presentation!)
- Potential Issues: Brief discussion of the issues you anticipate with this design direction.
- Next Steps: A brief timeline of your planned activities to prove-out your design by CDR.

Before delivering your presentation to your sponsor, you will first deliver it to your lab group. This will be graded, but will also serve as a final "dress rehearsal" for your sponsor presentation. After your (15 minute!) presentation, you will get feedback from your coach/advisor and peers so you can improve your delivery with your sponsor. Be prepared to take copious notes about their feedback in your logbooks!

If your sponsor requests that you make this presentation in person, please review the travel policies before making your plans.

As you prepare your PDR Presentation, review section 2.8 (Senior Project Presentations – Overview).

2.10 Failure Modes & Effects Analysis (FMEA) (1st quarter)

Failure Modes and Effects Analysis (FMEA) is a process for reviewing your design and finding how to improve it. You focus initially on ways in which the design might fail to perform its functions (failure modes). Then, you consider how these failures might affect the customer (including safety risks). Then, what might cause those failures to occur? The process allows you to focus on the most critical potential issues, so that your development efforts can be as efficient as possible. The FMEA can also allow you to
focus your analysis efforts while developing your detailed design. Your faculty coach/advisor will provide more information on developing an FMEA.

2.11 **Interim Design Review (IDR) (2nd quarter)**

Unlike the PDR & CDR, the Interim Design Review (IDR) is an informal status presentation in lab. You are expected to have made all the major decisions about your design that were left open from the PDR, but most likely you won’t have had time to select every component. There is no report associated with the IDR either. It is intended as a checkpoint to ensure your design is nearly complete, and to get feedback from your peers about potential issues (before you fully lock-in your design).

For your IDR, prepare a layout drawing of your overall design and each major component. Discuss:

- Brief review of the function and operation of your design
- Details about each major component:
  - Form, material, function
  - Anticipated manufacturing process
  - Analyses/tests completed
  - Remaining analyses/tests to do by CDR
- Concerns (what might not work out or might take too long?)

The goal of the IDR is to get feedback from your faculty coach/advisor and peers about your progress. Plan to spend most of your time taking notes about potential issues identified during the review. As you prepare your IDR Presentation, review section 2.8 (Senior Project Presentations – Overview).

2.12 **Structural Prototype (2nd quarter)**

Like the Concept Prototype, the Structural Prototype is an early prototype phase. In the auto industry, structural prototypes include the underlying structure of a new vehicle, coupled with rough prototypes of trim components. They are used to evaluate crash safety and vehicle dynamics, early enough in the design process that changes can be made to these critical systems without delaying production.

In senior project, the Structural Prototype could be either:

a) A rough version of your overall system, so you can see that everything fits together and will function as intended.

b) A final version of one or more key components, so you can start performing critical tests early and/or confirm your manufacturing plan for those parts.

It’s up to your team, in consultation with your coach/advisor and sponsor, to decide what is most important for you to show in this prototype. Your Structural Prototype, and associated test results, should be included in your CDR presentation.

2.13 **Critical Design Review (CDR) (2nd quarter)**

The CDR consists of three components: A written report, an oral presentation (with visual aids), and a structural prototype (already discussed in section 2.12).

2.13.1 **CDR Report**

The CDR report should contain all the information a third party needs to build your design without any other help. The report extends your PDR Report by adding chapters describing your final design and manufacturing and testing plans. New appendices include detailed part drawings and costs. Provide
sufficient information about parts and materials you plan to purchase so someone else could order them. If you do a good job on this report, you will have most of your Final Design Review (FDR) Report complete!

The CDR Report contains ALL information needed to build your design!

The CDR Report starts with the chapters of your PDR Report (revised as necessary). For each chapter that you updated from the PDR, please include an introductory paragraph describing any changes made. Your CDR should follow the outline shown Figure 8.

- Title Page – identify this as the Critical Design Review (CDR) report. Include a date
- Abstract or Executive Summary - updated to reflect that this is the CDR report
- Table of Contents
- List of Figures
- List of Tables
- Chapter 1, Introduction - updated to reflect that this is the CDR report
- Chapter 2, Background - updated based on feedback & new research
- Chapter 3, Objectives - updated, based on feedback & new information
- Chapter 4, Concept Design – updated, based on feedback & decisions made since PDR
- Chapter 5, Final Design – detailed description of final design
- Chapter 6, Manufacturing Plan – detailed description of how you will make your final prototype
- Chapter 7, Design Verification Plan – definition of planned tests & required resources
- Chapter 8, Project Management – focus on timeline and deliverables after CDR.
- Chapter 9, Conclusions – summarize the document and ask for sponsor agreement
- References (or, Works Cited)
- Appendices

Figure 8: Critical Design Review (CDR) Report Contents

More information about each chapter is given below:

- **Abstract** (or Executive Summary). Updated from PDR to reflect the new work completed and advisor/sponsor feedback.
  1) **Introduction.** Updated from PDR to include the new chapters and advisor/sponsor feedback.
  2) **Background.** Updated from PDR to include any new research and advisor/sponsor feedback.
  3) **Objectives.** Updated from PDR to reflect new information and advisor/sponsor feedback.
  4) **Concept Design.** Updated from PDR to include recent decisions and advisor/sponsor feedback.
  5) **Final Design.** New chapter about your final design. Here is where you explain what it is, what it does, how it works, and why you think it will meet all your specifications. Include:
    - A complete description of your final design, including clear labeled figures (3D isometric works well). Include more detailed descriptions of all major subsystems and components.
    - An explanation of the functionality of your design – what it does and how it does it.
    - For designs with electrical wiring, include wiring diagrams.
    - For designs with software, include flowcharts and/or pseudo-code.
    - A convincing discussion and explanation of your evidence that the design will meet each of your specifications. Common types of engineering evidence includes hand calculations, simulations, similarity to existing designs, or prototype tests. Describe any analyses or tests
and their results (e.g. safety factors), and include the details in an appendix. Use this section to justify your material and geometry choices.

- A discussion of Safety, Maintenance, and Repair considerations. Update your FMEA (section 2.10) and Design Hazard Checklist (section 1.8) and include them in the Appendix.
- A summary cost analysis (broken down by major component or subsystem) for your confirmation prototype. Include the full cost analysis including every component in an appendix.

6) **Manufacturing Plan.** New chapter explaining how you will make your confirmation prototype. Include sufficient detail so you could hand this to someone else and they could make this prototype for you (major challenge!!). Be sure to include:
   - Procurement – how/where you will purchase materials & purchased components.
   - Manufacturing – Step through the sequence of all manufacturing operations you’ll need to perform to make each part.
   - Assembly – discuss how you will assemble all components
   - Outsources – Discuss any plans to outsource manufacturing.
   Remember: you may not complete any electrical wiring that will carry more than 50 Volts.

7) **Design Verification Plan.** New chapter explaining how will confirm that your confirmation prototype meets all of your design specifications. Be sure to:
   - Discuss each of your specifications independently.
   - Describe all tests and their facility and equipment needs.
   - Include at least one test in which you will collect numerical data and perform data analysis and uncertainty propagation calculations.
   - Reference your DVP in the Appendix.

8) **Project Management.** Updated from your PDR to focus on the activities after CDR.

9) **Conclusions.** Updated from your PDR to reflect your new results & next steps.

- **References (Works Cited).** Updated from the PDR.
- **Appendices.** Updated from PDR. Your CDR should include at least the following appendices:
  - QFD House of Quality
  - Decision Matrices
  - Preliminary analyses and/or testing details
  - Indented Bill of Materials with part numbers
  - Drawing Package, including Assembly Drawing, exploded view Assembly Drawing, detailed part drawings for all manufactured or modified parts, and welding drawings.
  - Electrical schematics or wiring diagrams, if your design includes electrical components.
  - Flowcharts and/or pseudocode, if your design includes programming.
  - Links to product literature for all purchased parts.
  - A project Budget showing all planned material and part purchases, with part numbers and vendors identified for each. Indicate which component(s) in your BOM is supported by each purchase. This should be a shopping list that you could hand to someone else to make the purchases for you. It is NOT the same as your BOM.
  - Annotated (clearly explained) legible analyses and/or test results to support all design decisions. Explain what you are doing on each page.
  - Failure Modes & Effects Analysis
  - Design Hazard Checklist (updated)
  - Design Verification Plan
Gantt Chart

Ensure that your report is continuous in writing style, fonts, headings, verb tenses, etc. Any information you include (figures, tables, appendices) should be referenced in the text of the report. If it is not referenced in the text, it should not be in the appendix. We recommend that you stick to the suggested format, including the numbered chapters, unless it does not fit your project for some reason.

As you prepare your CDR Report, review section 2.5 (Senior Project Reports – Overview).

2.13.2 CDR Presentation

As just described, the CDR report provides all the details of your final design, so the CDR presentation only needs to hit the highlights. As with any professional presentation, you should prepare a concise, clear story about your design, with hidden back-up slides to answer questions if they arise. Plan (and practice!) your presentation to ensure you can present it in 15 minutes or less.

Your presentation should cover the following points:

- **Introduction:** Briefly review your project’s scope & goals (for a general audience).
- **Design Description:** Explain your design: What does it look like? What does it do? How does it work? Show lots of pictures/animations. Use your structural prototype.
- **Design Justification:** Summarize your analysis and testing to convince us that your design will meet each of your specifications. Focus on what you analyzed/tested and what you found.
- **Manufacturing/Cost:** Summarize how you will procure or make each component of your design. Give a simplified Bill of Materials to show the piece costs, and an overall budget to show total cost.
- **Testing:** Summarize your test plans (time, equipment, locations, etc.).
- **Potential Issues:** Briefly discuss any issues you anticipate with making/testing your design.
- **Next Steps:** Summarize major tasks and timeline through the end of the project.

Before delivering your presentation to your sponsor, you will first deliver it to your lab group. This will be graded, but will also serve as a final "dress rehearsal" for your sponsor presentation. After your (15 minute!) presentation, you will get feedback from your coach/advisor and peers so you can improve your delivery with your sponsor. Be prepared to take copious notes about their feedback in your logbooks!

If your sponsor requests that you make this presentation in person, please review the travel policies before making your plans.

As you prepare your CDR Presentation, review section 2.8 (Senior Project Presentations – Overview).

2.14 Risk Assessment / Safety Review (2nd quarter)

After your design is complete, your team needs to prepare a Risk Assessment. In this assessment, you will consider the operations that a user (or you, as the tester) will need to perform with your final design. For each operation, you’ll identify all risks present and then develop a plan for managing those risks. We’ll provide you software tools to guide you through this process.

After your coach/advisor reviews your risk assessment, you may be asked to meet with one of the campus technicians to discuss your risk management plan. If so, please bring the following to that meeting:

- Your risk assessment
- Your drawing package (especially, your assembly and exploded view drawings)
• Your wiring diagram (if you have any electrical risks)

During the discussion, take detailed notes of any suggestions from the technicians on how to improve the safety of your design, and come up with specific tasks after the meeting. Report the results of the meeting in a memo to your coach/advisor and the technicians.

### 2.15 Ethics Activities (2nd quarter)

During the second quarter, you will be asked to participate in some Ethics Activities. These may include team presentations on ethical case studies and/or individual ethics case study memos. A brief description of these are included here. Your coach/advisor will provide more details.

#### 2.15.1 Case Study Presentation (team)

Your team will explore a case study, prepare and deliver a presentation to the class, and lead a discussion on possible courses of action/outcomes. Your preparation and presentation should include:

- Summary of the case with necessary background information.
- Results of your research into other applicable case studies
- Exploration of the ethical questions/dilemmas related to the case, including relevant canons
- Discussion of possible solutions.
- Discuss what you think is the most ethical solution.
  - Use codes, history, personal experience to back up your points
  - What would the difficulties be in implementing your solution?
- Lead an extended class discussion about the ethics of each option.

Your presentation should be professional, last 15-20 minutes, followed by 15-20 minutes of in-class discussion. It is your job to be the teacher or facilitator for your selected case. You will be evaluated on:

- Explanation of the case and related cases/histories
- Analysis of ethics involved
- Thoroughness of recommendations presented
- Ability to lead an in-class discussion on the topic

#### 2.15.2 Ethics Memo (individual)

In engineering practice, we use engineering judgment to select the best option from a number of alternatives. Much of your college career has focused on learning analytical tools to help you make these decisions. However, engineering decisions often have effects that go well beyond the technical details. In these situations you sometimes face the difficult task of proposing and defending an unpopular approach to those in power, because you feel it is the best one for the customer, society, the environment, etc.

This assignment requires that you imagine yourself IN a professional situation where an ethical conflict exists. Write your assessment of the situation, and your personal recommendation, in the form of a memo to your boss, a colleague, or a customer (depending on the situation), as if you were the key character in the dilemma. Discuss in the memo your analysis of the situation with reference to the Code of Ethics for Engineers (ASME or NSPE) or other applicable Code of Ethics.

Select a relevant engineering case study of interest to you, study it, and think about what course of action YOU would propose if it was happening to you. Prepare a professional 2-page memo that includes:

- Discussion of the scenario.
- Clear identification of the ethical dilemma.
• At least three reasonable potential alternative actions.
• Discussion and justification of your preferred alternative.
• Appropriate references in the NSPE or ASME Code of Ethics.
• Conclusion.

2.16 Status Reports (2nd-3rd quarters)
While moving from the second to the third quarters, you will prepare a status report consisting of an oral Manufacturing and Test Review presentation in lab and a Project Update Memo to your sponsor.

2.16.1 Manufacturing and Test Review
At the end of the second quarter your team will make a short presentation in lab to report the status of your manufacturing and the details of your Test plans. The presentation should include:
• Status of component manufacturing (bring your hardware to show)
• Updated test plan, including locations and list of all necessary hardware for testing
• Safety checklist to be signed by your instructor prior to any testing (i.e., what you will do to safely set up a test).
• Updated schedule focusing on the on-time completion of the project.
This presentation will be scheduled through your faculty coach/advisor, and all students in a lab section are expected to attend.

2.16.2 Project Update Memo
In addition to the in-class presentation, teams are expected to keep their sponsors up-to-date with their status. While much of this is done during your periodic meetings, at the beginning of your 3rd quarter, each team should prepare a brief (3-5 page) status memo that updates your sponsor on your project. Since this memo is written well into the build phase of your project, it will report primarily on your progress through the build phase and planned testing. You should have taken a number of photos of your progress in constructing the product or system that you have designed, so the report can be written as a narrative accompanying these pictures. This is the one stand-alone report in senior design – it is completely independent of the CDR Report and the FDR Report. However, if you do it well, it can form the basis of your FDR Manufacturing section!

To write this report, review your CDR Report and then ask yourself: What’s changed? What’s been accomplished since then? The Project Update Memo should be a description of these changes and accomplishments, with accompanying photos. Also use this as an opportunity to update your Gantt chart and to highlight activities completed since CDR. Give your assessment of whether or not the project will be completed on time. If your budget has changed because of unforeseen components that you need to buy, you need to report this too.

2.17 Confirmation Prototype Review
The Confirmation Prototype Review is scheduled after you have finished manufacturing and assembling your confirmation prototype. You will show your faculty coach/advisor and safety technicians that you have carefully considered the safety hazards of your design and implemented all reasonable precautions to protect yourself and future users. In addition to your final assembled hardware, bring copies of these safety-related documents to the demonstration:
1. FMEA
2. Design Hazard Checklist (from your CDR Report)
3. Risk assessment
4. Design Verification Plan (DVP)
5. Individual test procedures (including safety precautions from Risk Assessment)

Make sure your hardware reflects all your design decisions in these documents!

2.18 ABET Activities (3rd quarter)

Senior Design Project fulfills many requirements necessary for the ME program’s accreditation by ABET (Accreditation Board for Engineering and Technology). In order for the department to receive accreditation we must assess student learning and outcomes; therefore, we administer a Senior Exam during the third quarter. This exam is required for all ME students and your exam results contribute to your ME 430 course grade. Preparation for this exam is similar to preparation for the FE (Fundamentals of Engineering) licensing exam.

Also as a part of accreditation, all senior project students must fill out a Senior Survey during ME 430. This is not graded, but completion of the survey is necessary to receive a grade for the course.

2.19 Operators’ Manual (3rd quarter)

Your design is not complete until you have fully documented the correct method of operation and identified any known safety concerns. Write an Operators’ Manual, similar to a car’s owner’s manual. Be sure to include lots of pictures and point out all safety hazards. This manual is where you can document the process you developed when you prepared your Risk Assessment.

2.20 Final Design Review (FDR) (3rd quarter)

The FDR consists of three components: A Confirmation Prototype, a written FDR Report, and a Project Expo Poster presentation.

2.20.1 Confirmation Prototype

Part of the culminating experience for senior design project is the process of bringing your design to physical form. The confirmation prototype you produce is therefore an important part of your deliverable in your Final Design Review. This prototype will be reviewed for:

- How well it matches your design intent
- Quality of workmanship
- Whether it allowed you to test to your specifications.

2.20.2 FDR Report

The FDR Report grows out of your CDR Report from the second quarter. In general, you will need to update your description of the design and drawings to account for any changes you have made during construction or after testing. Your Manufacturing Plan and Design Verification Plan chapters will lose the “Plan” and describe what you actually did. Your Conclusions chapter will get a major update to reflect what you suggest the sponsor do with your work now that your senior project is complete. The organization of your report might vary from the recommendation below, but should include all the elements listed. Please use your best judgment in creating your outline. Some standardization on format is necessary as copies of all senior projects reports will be kept in Digital Commons at the library. The content of your report should be similar to that shown in Figure 9. For format ideas, we recommend you review past Senior Project reports on Digital Commons through the library website at
http://digitalcommons.calpoly.edu/mesp/. As you prepare your FDR Report, review section 2.5 (Senior Project Reports – Overview).

- Title Page
- Confidentiality Statement – only for proprietary projects
- Disclaimer Page
- Abstract or Executive Summary – Updated summary of the full document
- Table of Contents
- List of Figures
- List of Tables
- Chapter 1, Introduction – Update for this final document
- Chapter 2, Background
- Chapter 3, Objectives
- Chapter 4, Concept Design Development
- Chapter 5, Final Design – Add a section to describe all design changes after CDR
- Chapter 6, Manufacturing – describe all procurement & build activities.
- Chapter 7, Design Verification – describe your tests and results.
- Chapter 8, Project Management – Update to describe your completed process.
- Chapter 9, Conclusions & Recommendations – Summarize the project and give recommendations.
- References (or, Works Cited)
- Appendices

**Figure 9: Final Design Review (FDR) Report Contents**

- **Abstract** (or Executive Summary). Updated from CDR to describe your full project.
  1) **Introduction.** Updated from CDR based on document changes.
  2) **Background.** Updated from CDR to include any new research.
  3) **Objectives.** Updated from CDR to reflect new information.
  4) **Concept Design.** Usually unchanged from the CDR.
  5) **Final Design.** Updated from the CDR to capture all design changes you made during manufacturing and testing.
  6) **Manufacturing.** Converted from the “Manufacturing Plan” chapter of the CDR. Include:
     - Description of your part procurement process & final budget status.
     - List of all of the manufacturing steps to create your confirmation prototype.
     - Description (& pictures!) of all major operations you used to build each component
     - Discussion of any challenges or lessons learned in the process.
     - Recommendations for future production of your design.
  7) **Design Verification.** Converted from the “Design Verification Plan” chapter of the CDR. Include:
     - Description of how you verified that your design meets its specifications.
     - Description of all tests and results, including pictures as appropriate.
     - Numerical data collection, data analysis, and uncertainty analysis for at least one test.
     - Explanation of any missing tests or specifications not met.
     - Discussion of any challenges or lessons learned in the process.
8) **Project Management.** Modified from the CDR. In this chapter, describe and assess (did it work?) the process you followed throughout this project. What worked well? What will you do differently on your next design project?

9) **Conclusions & Recommendations.** Significantly updated from your CDR. This should be several pages long and include your reflections about what the project achieved, what it didn’t achieve, and what you would do differently if you had it to do over again. Include a “Next Steps” section in which you advise your sponsor what to do next on this project.

- **References (Works Cited).** Updated from the CDR with any new references.
- **Appendices.** Your FDR report should include at least the following appendices. Changed items are in **bold**:
  - QFD House of Quality
  - Decision Matrices
  - Preliminary analyses and/or testing details
  - Drawing Package, including a Bill of Materials (BOM), Assembly Drawing, exploded view Assembly Drawing, and detailed part drawings for all manufactured parts. **This should reflect your final design, with any changes incorporated after CDR.**
  - Electrical schematics or wiring diagrams, if your design includes electrical components.
  - Flowcharts and/or pseudocode, if your design includes programming.
  - **Final code for any software you developed.**
  - Links to product literature for all purchased parts.
  - A project Budget showing all actual material and part purchases, with part numbers and vendors identified for each. Indicate which component(s) in your BOM is supported by each purchase.
  - Legible analyses and/or test results to support all design decisions, with explanations.
  - Failure Modes & Effects Analysis
  - Design Hazard Checklist
  - **Risk Assessment**
  - **Operators’ Manual**
  - Design Verification Plan & Report (all columns completed)
  - Gantt Chart (**updated to what actually happened in the project**)

Once your report is complete, convert it to a single PDF file. Please use Adobe Acrobat (available on all ME lab computers to save the file, since it will create a much smaller file size than other PDF creators. Then, submit that file in ALL of these ways:

1) Upload it to PolyLearn.

2) Email it to your sponsor, with a copy to your copy. Ask your sponsor whether s/he would also like a printed copy. If so, print and give this to them at the Expo.

3) Upload it to the library ([https://digitalcommons.calpoly.edu/cgi/ir_submit.cgi?context=mesp](https://digitalcommons.calpoly.edu/cgi/ir_submit.cgi?context=mesp)). You’ll need to provide your faculty coach/advisor with receipts showing you (a) paid the fee and (b) uploaded your file.

**Proprietary Work:** If your project is proprietary and your sponsor does not want the report available in the library, then should add the Confidentiality Statement just before the Statement of Disclaimer. For the Library Upload, submit **only the Title Page and Confidentiality Statement.** DO NOT include the abstract, unless your sponsor approves that for publication. You still have to fill out the other forms, and you still have to pay the fee. Make sure you check the box on the library form that indicates this report is not for public release.
Sample Pages:

The next three pages contain samples to help you with the format of your report. They contain the basic text and margins required. You are free to change the format of the title page. The pages included are:

- The Title Page
- The Disclaimer Page
- Confidentiality Statement

Remove the highlighted RED labels on each page before using them.
Steam Powered Lawn Mower

by

John Q. Student
Jesse Q. Student
Pat Q. Student

Mechanical Engineering Department
California Polytechnic State University
San Luis Obispo
2011
Statement of Confidentiality

The complete senior project report was submitted to the faculty coach/advisor and sponsor. The results of this project are of a confidential nature and will not be published at this time.
Statement of Disclaimer

Since this project is a result of a class assignment, it has been graded and accepted as fulfillment of the course requirements. Acceptance does not imply technical accuracy or reliability. Any use of information in this report is done at the risk of the user. These risks may include catastrophic failure of the device or infringement of patent or copyright laws. California Polytechnic State University at San Luis Obispo and its staff cannot be held liable for any use or misuse of the project.
2.20.3 Project Expo Poster Presentation

The Project Expo is the culminating event of the Mechanical Engineering Department’s three-quarter Senior Design Project. Your team will present your senior design project in a poster session with accompanying hardware. If there is a compelling reason that hardware cannot be at the event, then photos and/or video should be displayed. Advisors, sponsors, other faculty, and guests will attend the Expo. We encourage you to invite your friends and family as well. (In our experience, parents of graduating students love to come see their child’s magnum opus.) Your faculty coach/advisor will let you know the specific timing/details of the day, but you should expect these key activities:

1) Setup: All posters and hardware should be set up during a specific time window.
2) Safety Review: Teams who want to ‘run’ their systems during the Expo should be prepared to review their safety plan with the senior project coordinator and safety technician (see below).
3) Grading: All students should leave the Expo area during the grading time, when a panel of ME faculty grade the posters.
4) Public Expo: At least one team member should be present at your poster throughout the Public Expo to answer questions.
5) Cleanup – all teams should hand off their hardware to their sponsors and clean up their area at the end of the Expo.

Poster Design

All teams should create a 36” x 48” poster. PowerPoint is an effective tool to create your poster. You can also use Adobe software and others. You should review your poster with your Sponsor and Coach/Advisor prior to printing it, to be sure they approve of the content and layout.

At a minimum, your poster should include:
- Overview of the Problem/Need
- Description/illustration of your final design
- Your engineering analysis
- Your key test results
- Conclusions/Recommendations

Many teams also find it helpful to include an illustration of how your design has evolved through the design process.

Posters will be graded by a faculty panel using two main criteria:

1) **Organization / Visual Appeal:** The posters should be neat and professionally arranged so that they are easy to understand. There should be a logical progression through problem definition, conceptual design, and final design; with analysis, testing, and conclusions shown. Figures should be clearly labeled and all text should be clearly readable from 5-10 feet away.

2) **Technical Content:** This is an engineering project, so your poster needs to highlight the engineering content. This includes analysis, decision techniques, prototype testing, and so on. Your poster should use the technical content to explain why your final design is the best solution. Final test results are essential.

A third category for your Expo grade will come from your confirmation prototype(s). Specifically, graders will assess the quality and completeness of the prototype.
**Poster Do’s:**
- **DO** use large font sizes. It should be clearly readable from 5-10 feet away.
- **DO** include lots of pictures and minimal text (someone can ask you if they want more information)
- **DO** include titles for different sections of the poster to guide the reader
- **DO** organize your content so that it is easy to follow.

**Poster Don’ts:**
- **DON’T** use a background color. Keeping it white allows your dark text to be more readable, uses less ink, and enables faster poster printing.
- **DON’T** use any font sizes smaller than 24
- **DON’T** use a lot of text (no full paragraphs!). Keep it brief; you can add verbal explanations.

**Poster Printing/Mounting**
Posters will be printed in the plotters in the ME labs. For best appearance, the ME department will load glossy photo paper into specific plotters on specific dates in the week leading up to Expo. You’ll be asked to sign up for a 30-minute time window to print your poster. There are instructions near each plotter to help you print your poster. Please make sure you arrive early with your file ready to print!

After printing, your poster will need some time to dry, and then needs to be glued to a flat (NOT tri-fold) support board using spray adhesive. Your coach/advisor will provide you with the board, spray adhesive, and instructions during the last lab before the Expo. Your poster will need to be printed prior to this lab!

Note that the poster foamboard is NOT recyclable. If neither you nor your sponsor want your poster after the Expo, please give it to your Coach/Advisor so we can re-use it next year to create new Concept Models in ME 428!

**Attire**
The Project Expo is a formal Exposition, and project sponsors and other industry representatives will be traveling to see the event. Please dress appropriately and professionally. Business Casual is acceptable.

**Expo Safety Review**
If you have requested to demo (run) your confirmation prototype during the Expo, you will need to prepare the items listed in Figure 10 and have printouts at your display for this final safety review. During the Safety Review, the senior project coordinator and safety technician will review your display. If they approve of your safety plan and hardware, an “OK TO RUN” sticker will be added to your poster. If you do not receive one of these stickers, you MAY NOT run/operate/actuate/demo your prototype during the Expo.

---

**Expo Safety Review Checklist (to ‘run’ at Expo)**

- [ ] Safety Plan (see sample in PolyLearn)
- [ ] Confirmation Prototype with Appropriate Safety Labels & Placards Attached
- [ ] Risk Assessment

---

**Figure 10: Expo Safety Review Checklist**
At the End of the Expo
In addition to being present to show off your work to Expo attendees, you should deliver your Confirmation Prototype and Operator’s Manual to your sponsor at the conclusion of the Expo. Ideally, you will also hand them a copy of your files and the FDR report so you can be completely finished!

Figure 11: Scene from a successful Design Expo

2.21 Senior Project Completion
After the Senior Design Expo, you still need to submit your final report to the library, return any borrowed equipment, clean up your project work areas and complete a few other necessary tasks. A checklist of the required project wrap-up activities is shown on the next page. Your faculty coach/advisor cannot issue a grade for the class until all of these activities have been completed and signed off. Please make sure to do this in a timely fashion.

To submit your project report to the library, complete the following steps:
1) Check your report format using the “Senior project information packet” on the library website (http://digitalcommons.calpoly.edu/seniorprojects/).
2) Follow the “Detailed guidelines for submitting your senior project” (http://lib.calpoly.edu/help-and-support/senioprojects):
   a) Complete and print the “Senior project requirement form” on the library website.
   b) Pay the senior project report fee (at the cashier’s window in Building 1 OR online). Make a copy of the receipt for your record, and attach the original to the “Senior project requirement form.”
   c) Bring the form and attached receipt to your faculty coach/advisor (not the department office).
   d) Upload your report to DigitalCommons:
      i) If your project is NOT proprietary: Upload a PDF of your complete report to DigitalCommons (see detailed instructions at the end of the “Senior project information packet”). Be sure to copy and paste your Abstract in the appropriate place on the form so it can be searchable.
ii) If your project IS proprietary: Upload a PDF containing ONLY the title page and confidentiality statement. DO NOT include your abstract in the form, unless your sponsor has approved it for external publication.
Table 2: Senior Project Completion Checklist

Before a final grade can be issued by your faculty coach/advisor, your team must complete all of the items on this checklist and bring it to your faculty coach/advisor for review.

Project/Team: ________________________________________________________________

<table>
<thead>
<tr>
<th>✓ Task</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prototype tested to verification plan (attach copy of final DVPR).</td>
</tr>
<tr>
<td>Operators’ Manual (&amp; safety precautions) included in FDR Report Appendix (coach/advisor to confirm).</td>
</tr>
<tr>
<td>Final hardware and any extra components delivered to Sponsor (attach sponsor email).</td>
</tr>
<tr>
<td>Expo poster delivered to Sponsor.</td>
</tr>
<tr>
<td>FDR Report delivered to Sponsor (copied to faculty coach/advisor).</td>
</tr>
<tr>
<td>Final FDR Report and Expo Poster uploaded to ME 428 PolyLearn site (faculty coach/advisor to confirm).</td>
</tr>
<tr>
<td>Final Budget Spreadsheet (with actual costs) emailed to faculty coach/advisor.</td>
</tr>
<tr>
<td>Signed library form and payment receipt delivered to coach/advisor (restricted access if NDA in place).</td>
</tr>
<tr>
<td>FDR Report *.pdf file uploaded to the digital commons (attach e-mail confirmation). (if restricted access, pdf only contains title page and confidentiality statement. No abstract!)</td>
</tr>
<tr>
<td>Fabrication area cleaned up &amp; tools returned to shop.</td>
</tr>
<tr>
<td>Shop Tech Signature: _________________________  Print Name:  _________________________</td>
</tr>
<tr>
<td>Test equipment returned.</td>
</tr>
<tr>
<td>Electronics Tech Signature: _________________________  Print Name:  _________________________</td>
</tr>
</tbody>
</table>
3 Senior Project Resources

This chapter provides information about the general senior project resources available to all ME senior project students.

3.1 Labs & Support Facilities

This section provides brief descriptions of the campus facilities that you may find helpful as you complete your senior project.

3.1.1 Bonderson Student Project Center

The resources of the Bonderson Student Project Center (Building 197) are available to you to complete your senior design project. The center offers senior project team locked storage in three sizes:

- Storage lockers (1x1x2 ft)
- Outdoor cages (3x4x3 ft)
- Workbenches/cabinets in dedicated project rooms (only for large projects)

Storage will be assigned based on availability and the specific needs of your project. Contact the Student Shop Manager (Eric Pulse) to reserve space.

3.1.2 24-hour Computer Labs

All ME students have access to the following labs 24/7 with their poly card ID:

- 13-107
- 192-120
- 192-131
- 192-132
- 192-134

By using any of these labs outside of class times, you agree to perform an hour cleaning one of the labs. Contact Larry Coolidge (in 13-103), or the ME dept. office to sign up for your hour of clean up each quarter. The computer labs all have these software available:

- CAD: Solidworks, CATIA, ProE…
- Analysis: MATLAB, Abaqus

3.1.3 Sponsor Communications

Large Files - Sometimes your sponsor wants to send you a large file or you want to send one to them. Many email systems limit the file size that can be received. To transfer large files to- or from- an off-campus site, use the FileSender tool (see https://servicedesk.calpoly.edu/filesender for info).

Audio/Video Conferencing –To arrange screensharing, audio-, and video-conferences, use the Zoom Conferencing tools (see https://servicedesk.calpoly.edu/zoom-video-and-web-conferencing for info).

3.1.4 Conference Rooms

Room 192-133 is a small meeting room available for senior project teams to reserve. Visit the ME Department (in 13-254) to reserve the room and get access. The facilities in this room include:

- Speaker Phone (on table) with cell phone connector.
- Fax for long distance communication
- 8-person Conference table with built in AC and Ethernet for your notebook
- A computer with design software
ME 428/429/430 Senior Design Project

- Color Printer & Scanner
- Digital camera connection & software
- Smart Board

**Important: Do not use dry erase markers on the smart board!**

Digital cameras are available for checkout from media services in building 2, room 9.

Room 13-124B is another meeting room available for senior project team video- and audio-conferences. Visit the ME Department (in 13-254) to reserve the room. You’ll need to pick up the key before your meeting and return it after.

In both rooms, the telephone rules are:
- The FAX number is **805-756-5606**
- If you need to use the phone then:
  - Have the sponsor call you
  - Call only toll free numbers
  - Make collect calls
- Don’t talk more than necessary (i.e. plan the call, don’t waste time)
- Log all outgoing calls, including faxes sent

If you have a weekly teleconference scheduled with your project sponsor, please write it on the white board so other teams know not to schedule theirs at the same time.

The library provides several useful meeting rooms for teleconferences with your sponsor. You can read more about them at [http://lib.calpoly.edu/study-spaces-and-tech/reserve/](http://lib.calpoly.edu/study-spaces-and-tech/reserve/).

### 3.1.5 Audio Visual Equipment

If you require any audio/visual equipment including digital cameras, video recorders, etc. these are available through media distribution services. Information available at [http://www.mds.calpoly.edu/](http://www.mds.calpoly.edu/).

### 3.2 Manufacturing Resources

This chapter provides an overview (with links) to the campus facilities that can be used to build the final prototype of your senior design project.

**Important: Do NOT work on your senior project hardware at home!**

#### 3.2.1 Student Project Shop Facilities (Aero Hangar and Mustang 60)

The Hangar shop and Mustang 60 shop are the main fabrication facilities available to you for manufacturing your senior project prototype. The shop is open to all, regardless of abilities, but for safety reasons, shop access requires completion of the License to Drill (Red Tag) Tour & Test. Your senior project will likely require access to more machines, so all ME senior project students are required to obtain the License to Mill (Yellow Tag) before the end of ME 428. This will give you access to the milling machines & lathes for the rest of your time at Cal Poly. For information about the shops, check out their website at [https://machineshops.calpoly.edu/](https://machineshops.calpoly.edu/).

**All ME Senior Project Students must earn their Yellow Tag by the end of ME 428**
The Student Technicians ("Techs") can provide help and guidance in the manufacture of your project. You will build it yourself and possibly learn new skills, techniques and "tricks" through Cal Poly's "Learn by Doing" philosophy.

If there is a more complicated component that either requires high precision or is safety-critical and you do not feel you are qualified to build it, you have three options:

1) Discuss the manufacturing with the Techs. They may be able to find a more efficient, effective way of manufacturing it that you can perform yourself.

2) If the Techs cannot help you to do the manufacturing yourself, your project can “hire” a Tech to build it for you. This will require a paid “fee for service” contract with a student technician, so requires approval by your sponsor and your faculty coach/advisor. See Contract Fabrication, below.

3) In some cases, your sponsor will have access to more advanced manufacturing facilities and will build some of the components for you. This is acceptable, but be sure to discuss it with your faculty coach/advisor.

If you have any questions about the shops, call the Student Projects lab office at (805) 756-5634.

**Shop Procedures and Safety Tests**

In order to take a tour and test to use the Shop you must:

- Wear appropriate clothing for the Tour. If you wear shorts, open-toed shoes or excessively loose clothing or loose jewelry, you WILL NOT be allowed to take the Tour and Test for safety reasons.
- Arrive on time. The Tech giving the tour won’t let you join late. The Shop Safety Tour and Test takes approximately three hours and is limited to the first FIFTEEN (15) people who arrive promptly.

The **License to Drill (Red Tag)** Tour and Test is the REQUIRED standard introduction to the Hangar Shop and has no prerequisites. You MUST read the Red Tag Tour and Test Manual prior to your tour and safety test. You will most likely fail the test if you do not take the time to read the Red Tag Tour and Test Manual. This Tour and Test introduces you to many stationary and hand tools that allow you to fabricate a wide variety of materials in many ways. It DOES NOT include machining or welding tools.

The **License to Mill (Yellow Tag)** Tour and Test allows you to expand your fabrication skills into machining and welding. You MUST read the Yellow Tag Tour and Test Manual prior to your tour and safety test. You must have a REQUIRED minimum of 10 hours of Red Tag shop use on record to qualify for this tour and test. Red Tag qualified students who have demonstrated competence on hand and stationary power tools using in the shop may take the Yellow Tag Tour and Test. Yellow tags allow students to use any manual machine in the shop if they are properly supervised.

**Safety Reminders**

Whenever you are working in the shops, please follow these safety rules:

- Wear appropriate clothing. If you wear shorts, open-toed shoes or excessively loose clothing or loose jewelry, you WILL NOT be allowed to use the shop.
- Have your set-ups checked by a Tech before beginning any operation.
- Ask questions if in doubt about safety or operations or when you are unfamiliar with a tool.
- Wear safety glasses at all times in the shop.
Manufacturing Tips So You Can Finish Your Project

- Begin your project well in advance, as tool and machine time can be limited.
- Discuss your plans with the Shop Techs early. They may know a “trick” or tool that could save you lots of time.
- Design your project for tools that you know how to use. It's OK to learn to use one or two new tools in your project, but don't design the majority of the project to be built by processes or machines that you don't know how to use. The shop Techs are there to teach you, NOT to do your manufacturing for you!
- Techs want you to succeed. They will help you, but they won’t “bail you out”. As they say, “Poor planning on your part does not necessarily constitute an emergency on my part.”
- As a rule of thumb, if you’ve never done a process before, it will take FOUR TIMES as long as you think! If you have done it before it will take only THREE TIMES as long as you think! This is not an attempt at humor, this is a reality! We see it every quarter.
- Work on building your prototype as early as you can, it gets harder to check out the tools that you need as the shop gets busier near the end of the quarter.

Important: Triple how long you think any machine shop project will take.

3.2.2 Additional Campus Resources

There are several other departments in the university who have manufacturing resources that can support senior project students.

Industrial & Manufacturing Engineering (IME)

The IME department has plastic and metal 3-D printers, a foundry, welders, and CNC milling machines. Some of these can be used for specific senior project activities. Start by talking to your faculty coach/advisor or professors from your IME classes.

Industrial Technology & Packaging (ITP)

The ITP department has injection molding, vacuum molding, and other plastic manufacturing tools. In addition, they have a water jet cutter available for campus use. Talk to your faculty coach/advisor or check out their website at https://www.cob.calpoly.edu/undergrad/industrial-technology/.

Innovation Sandbox

Innovation Sandbox, on the second floor of the Bonderson building, is a great resource for all campus design teams. They offer free 3D printing in addition to other resources. Their website is https://cie.calpoly.edu/learn/innovation-sandbox-2/.

3.2.3 Using the 3D Printer, Laser, and Vinyl Cutters in Mustang 60

Instructions for using the rapid prototyping tools can be found in the Mustang 60 shop. These machines must be reserved ahead of time, up to a week in advance. Plan ahead and be proactive to use these popular tools. To speed up your time on the laser, the appropriate Illustrator Template is available on the ME Dept. Read-Only Drive: (R:\Mustang 60 Laser Template\Mustang60LaserTemplate.ait). Using this file to start your Illustrator files will save time and keep everything running smoothly.
Applicable costs:
- $2/linear foot of Self-Adhesive Vinyl Sheeting (15” wide)
- $0.05/gram of PLA Printer Filament ($1 minimum per print)

3.2.4 Contract Fabrication

The Student Projects Shop does offer some contract fabrication services for senior projects. This service is provided for parts that are beyond the capability of your team to fabricate including CNC, complex welding, and precision machining. This service is not supposed to replace the “learn by doing” nature of these projects. These services must be paid for by the project sponsor. To utilize this service follow the guidelines below.

- Consult with a Student Shop Tech early on in the process to determine if you do in fact require this service, or if there is a simpler way to manufacture your part that you might be able to accomplish on your own.
- Get a quote from the Tech on the cost of producing your part and an estimate for the turnaround time. Tech time will cost your project $28/hr. This does not include materials or tooling.
- Produce complete drawings, CAD, and/or datasets as requested by the Tech.
- Complete the Fee for Service Agreement available in the Mustang 60 Office.
- Schedule the job with the Tech.

Remember: The Student Techs will give you what you asked for (and Paid for) as described in the project documentation you provide them with. They will not give you what you “need.” That is to say that accurate and thorough CAD/drawings will go a long way in receiving your parts in a usable, timely manner.

CNC Machines
- CNC machinery is restricted to skilled machinists, you should be able to operate both CAD and Manual Machines without assistance before considering applying for an apprenticeship to be trained for our machines.
- Start on your project as early in the quarter as you can!
- Submit your project design as a CAD file for consideration at least a week in advance of your need for a decision, NOT your due date. MINIMUM Turnaround time for CNC work is 2 weeks IN ADDITION to this review period.
- Turnaround time varies wildly depending on your experience in our shop, the complexity of the process, Tech availability, time considerations for other CNC projects and other factors. Techs are students, and often the ones working on CNC projects have Senior Projects of their own.
- All decisions are FINAL, there is no appeals process.
- Have a contingency plan in place to manufacture your project using available manual machines and tools. Start on your project as early in the quarter as you can.
- Your CNC project must be approved by the CNC Supervisor Technician or Eric Pulse.

3.2.5 Rapid Prototyping (3-D Printing)

The ME Department has three high-quality rapid prototype machines available for use on your project. The capabilities of these machines are listed in the table below. Prices apply to industry-sponsored senior projects. Consult your faculty coach/advisor for details.
<table>
<thead>
<tr>
<th></th>
<th>SST 768</th>
<th>SST 1200es</th>
<th>Eden 250</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity (Size) (in.)</td>
<td>8x8x12</td>
<td>10x10x12</td>
<td>9.8x9.8x7.8</td>
</tr>
<tr>
<td>Resolution (in.)</td>
<td>0.010</td>
<td>0.010</td>
<td>0.004-0.008 (direction dependent)</td>
</tr>
<tr>
<td>Material Type</td>
<td>ABS</td>
<td>ABS</td>
<td>Photosensitive Resin</td>
</tr>
<tr>
<td>Material Cost</td>
<td>$6.44/in³</td>
<td>$6.44/in³</td>
<td>$.33/g</td>
</tr>
<tr>
<td>Maintenance Fee per setup</td>
<td>$61.00</td>
<td>$61.00</td>
<td>$61.00</td>
</tr>
<tr>
<td>Technician Fee per setup</td>
<td>$45.00</td>
<td>$45.00</td>
<td>$45.00</td>
</tr>
</tbody>
</table>

**Procedure for scheduling a rapid prototype part build:**

1) Review your drawing with your faculty coach/advisor & obtain his/her signature.
2) Take the signed drawing of your part to Larry Coolidge in 13-103 (756-1260) along with a high resolution .STL file (ask your faculty coach/advisor if you are not familiar with this format).
3) A good part size is around 4x4x4 inches.
4) The sponsor will be required to reimburse the department. Fill out the Client Order and Service Agreement Form with your Senior Project account number.
5) To schedule time on the machine with Larry Coolidge, use the Cal Poly Calendar system:
   a. Login to the my.calpoly.edu portal
   b. Select Email and Calendar
   c. Calendar
   d. New appointment
   e. Schedule
   f. Enter lcoolidg in Attendees
   g. Pick a time when Larry is available
   h. Save

For more information, visit [https://www.calpoly.edu/~lcoidl/Careers.htm](https://www.calpoly.edu/~lcoidl/Careers.htm).

### 3.3 Material Resources

- **Scrap Bins**
  There are scrap bins near each shop (ask a Tech for the location) that have metal and other scrap materials that are free for the taking for use on your Senior Design project.

- **Surplus Materials**
  There is a collection of surplus material (leftover from other projects) that is sold by weight (at very competitive prices!) by the shops. But, properties are unknown. Ask a Tech.

- **Heilman’s Salvage and Metals**
  - 6450 Rocky Canyon Road, Atascadero
  - (805) 466-4893

- **McCarthy Steel**
  - 313 South Street, San Luis Obispo
  - (805) 543-1760

- **Web Resources**
o A few websites that have been used by the ME department and student clubs are listed below. This is by no means a comprehensive list but it is a good starting point.

a) McMaster Carr
   Almost anything you could imagine. Freakishly fast delivery times. But, expensive.
   http://www.mcmaster.com/

b) Online Metals
   Good for small orders of aluminum and steel structural shapes and tubes.
   http://www.onlinemetals.com/

c) Fiberglass Hawaii
   Fiberglass, carbon, Kevlar, resins, molding materials…
   http://www.fiberglasshawaii.com/

3.4 Testing Resources
Designs are verified by some combination of analysis, similarity to existing hardware, inspection, and testing. It is a requirement of the ME senior project class that every project includes at least one test with numerical data collection, data analysis, and uncertainty propagation.

This section briefly describes mechanical inspection and testing resources available to senior project teams in the mechanical engineering department at Cal Poly.

3.4.1 Testing Consultants
The mechanical engineering department employs consultants that can help you with questions on manufacturing and testing of your project. Testing is a critical phase of these projects and you must start preparing your test plan parallel to your design activity. The testing consultant can help you plan and perform your design verification. Ask your faculty coach/advisor for contact information.

The Cal Poly Statistics Department provides free consulting services to the campus community. Contact statconsulting@calpoly.edu to set up an appointment or find out their office hours.

3.4.2 Dimensional Inspection or Measurement
Engineering parts and systems are built to print or drawing with dimensions and tolerances. Parts and systems are inspected to verify they meet drawing requirements and thus will function as the designer intended. The mechanical engineering department has measurement or inspection equipment available for student teams. This equipment is in the hangar or shop facilities and is described briefly below.

Scales and Tape Measures
The student shop has a variety of scales, squares and measuring tapes. These can be used to things like basic lengths, spacing, clearances, bores, and hole patterns. Dimensional inspection to interface requirements is usually the first thing after completion of hardware prior to assembly any other mechanical testing.

Calipers and Micrometers
More accurate dimensional measurements of parts are made with calipers and micrometers which are also available in the hangar.
Granite Surface Plate
The hangar also has a small granite surface plate which serves as a flat reference or zero datum for measuring parts. This dimensionally stable flat part is used in conjunction with measuring instruments.

Height gage and Dial Indicators
The height gage is similar to a caliper but has a flat base and thus is most often used in conjunction with a surface plate or “ways” of machines tools. Dial indicators are used similarly and have a variety of bases (including magnetic) to attach to your hardware directly to make measurements of heights and run-out. These come in a variety of travel and accuracies. These could be used to measure the deflection of a loaded structure at critical locations.

Weight and Mass
Part weight and mass are critical design information for many mechanical engineering components and systems. There are a variety of scales in the ME department.

- Engines Lab
  - large blue digital floor scale that has a capacity of 1000lb
  - two small precision scales or balances
- 13-124
  - a mechanical Toledo scale that has a capacity of about 500lb

3.4.3 Mechanical Testing
There are a variety of resources in the mechanical engineering department for materials characterization and structural proof testing. Most of the structural testing equipment and associated instrumentation are housed in the composite and structures lab, 192-135.

Hardness
Recall that hardness and tensile strength are related for materials like steel. Also remember wear and contact stresses are functions of hardness as well. The hangar has a hardness tester that can be used to measure the hardness of material samples.

Load Frames
The composites and structures lab in 192-135 has two tensile test machines that can be used to test both material coupons and structural components. Use of these machines require appointments an appointment made two weeks prior to your planned test date. To set an appointment you are required to have a test plan that includes a detailed sketch of your setup that includes tooling and instrumentation needs. Visit the LAB TA if one has been hired usually office hours posted next to the door of 192-135 door or Dr. Mello the current lab coordinator in an in an office hour.

Small Instron Tensile Test Machine
A 2000lb mechanical load frame is available for tensile testing. This machine is pictured below. It has wedge action grips which can used to pull on small specimens or structural components in tension only. Note the grips can be removed and purpose built tooling installed for testing of small structural components. Load can be recorded along with cross-head displacement. This machine is best suited for quasi-static tests. This machine has upgraded controls and a front panel which is user-friendly. Note the new “on switch” is at the back of the black box on resting on the table top. This machine is lead-screw
based and can produce forces that can cause injury. Do not use this machine without permission and a safety briefing from an instructor.

![Instron Servo-Hydraulic Test Machine](image)

**Figure 12: Intron Servo-Hydraulic Test Machine**

**Servo-Hydraulic Load Frame**
A servo-hydraulic load frame is available for higher loads up to 22,000 lb. This machine has sophisticated controls and can be used for fatigue and other static and dynamic tests. This machine has hydraulic grips that grasp coupons or tooling stubs that are a maximum of .25in thick by 1.0in wide with a grip length of 1.-1.5inches. Dedicated flex test tooling is also available for performing small three point bending tests such as ASTM 790 for characterizing polymer materials.

This machine is instrumented to measure load, cross head displacement and strain via clip on extensometers. Strain can also be measured using strain gages. A dedicated PC equipped with a NI/LabView hardware and software has virtual instruments or VIs which can be used to record values from strain and load instrumentation. Operating procedures are documented and available but use must be coordinated with faculty, technicians or trained student technicians as this machine is capable of generating tremendous loads and strain energy.
See the included attachment which has detailed instructions for performing a tensile test using the hydraulic test machine with load, extensometer and two strain gages as instrumentation.

**MTS 100kip Tensile Tester**
For very large loads the Civil Eng. dept. has a 100kip load frame. If you need to use this machine, please contact Dr. Dan Jensen in Civil Engineering.

**Torsion**
The composites and structures lab has a small Tinius-Olsen torsion tester. This mechanical machine can be instrumented to record load and twist. The machine can be fitted with a 500lb load cell to measure torque with its given lever arm. The gear reduction unit allows the user to many times simply twist the handles to provide the necessary torque to the hardware.
The composites and structures lab has an 8 foot square load floor for bolting structures down for testing. The interface is ½ inch T-nuts which go in metal slots in the floor. Load application can be performed using hanging weights and electric actuators or things like hydraulic “bottle” jacks. The floor has insert fastener maximum loads of about 2000lbs in any direction. All test set-ups again must meet faculty approval for safety considerations. The photo below shows a purpose built pendulum tester bolted to the strong floor.
Electric Actuators
Two electric actuators are available for testing. These have a 2000N capability and a 300mm stroke. These are picture below. They are lead screw based and the user pushes the buttons to raise and lower the actuator. These could be bolted between a structure and the load floor for proof testing.

Figure 16: Electric Actuators

Dynamic testing
The Vibrations Lab (13-101) can be used by permission from the lab coordinating instructor Dr. Hemanth Porumamilla. The equipment available are:
- Accelerometers
- Shake Tables
- Drop Tester
- DAQ systems

Simpson Strong Tie (SST) Strong Frame
The Construction Management Department has a Strong Frame that can be used to attach equipment which needs to be suspended under loads. Contact Professor Jason Hailer at jhailer@calpoly.edu for details.

3.4.4 Test Equipment Available for Checkout
To support your other test equipment needs, the department has a collection of mechanical test instruments available for checkout from Larry Coolidge (lcoolidg@calpoly.edu) or Ben Carr (bwcarr@calpoly.edu) in 13-103. Table 3 provides a list of the instrumentation that may be borrowed for use on your senior project. You will need to complete an Equipment Loan Agreement, which requires your faculty coach/advisor’s signature to start the checkout process.
<table>
<thead>
<tr>
<th>Group</th>
<th>Instrument</th>
<th>Notes or Description</th>
<th>Source</th>
<th>PN</th>
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<td>Omega</td>
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<td>Omega</td>
<td>DFG35-100</td>
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<td>LC101-50</td>
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<td>Omega</td>
<td>LC101-2K</td>
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<td>No Outputs</td>
<td>Omega</td>
<td>DP25B-S</td>
</tr>
<tr>
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<td>Load Cell Indicator</td>
<td>AO</td>
<td>Omega</td>
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<td>HHT13</td>
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<td>Digital Strain Indicator</td>
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<td>CS500P</td>
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</table>
4 Supplemental Reading

4.1 Design Process and Methodology

The engineering design process is a type of problem solving which can be summed up by five basic steps:

1) Establish a need
2) Explicitly state the problem
3) Generate possible solutions
4) Evaluate the solutions and pick the best one
5) Document the work

In reality the process of designing a mechanical, electrical, electro-mechanical, software or any other type of engineering system is more complicated and certainly not linear. In this class you will gain experience with the engineering design process by actually experiencing it as you solve an externally supplied engineering design problem. The problems are real and do not have a single “right” answer. Instead we will apply a formal (although nonlinear) process to find the “best” answer over a 30-week period. The flowchart shown below from “The Mechanical Design Process” by David Ullman gives a more complete picture of the steps of the engineering design process. Note the many arrows on the flowchart that point back towards the beginning of a project. This is an important and sometimes frustrating aspect of the design process which you will all experience in this class. Hopefully with guidance from your faculty coach/advisor, you can appreciate the effectiveness of this process and not be bogged down in frustration.
Figure 17: ME Senior Design Process
4.2 Working on a Team

4.2.1 Background and Motivation

Although students have likely worked together on team-based projects prior to their Senior Design Project experience, it is just as unlikely that they have done so for 30 weeks. The success of the project is in large part determined by the success of the team. It is therefore important that all students in the Senior Design Project course have an understanding of teaming skills, knowledge and attitudes. Katzenbach defines a team as “… a small number of people with complementary skills who are committed to a common purpose, performance goals, and an approach for which they hold themselves mutually accountable.”

Teaming, especially in engineering, is necessary to complete any reasonably complicated task whether it is designing a new product, setting up a new production process or implementing a new management organization. In this class we are focusing on the design process and therefore we will focus on the design “team.” Most of the deliverables for this class are “team” not individual items. Your ability to perform as part of a high performance team has a direct bearing on the success of your project. Most of the project failures and poor results in the past can be directly attributed to poor performance of the teams and most of the successes come from teams that perform at a high level. It is essential for you to have an understanding of teams and team processes and to develop your skills as a team member and practice them on your design team during this class. Once you develop these skills, you will be able to apply them for the remainder of your career. An excellent reference for engineering students is provided by Levi, et. al. and much of what appears here comes from their manual on Student Team Work.

4.2.2 Team Development Stages

In the 1960’s, Bruce Tuckman a Professor of Education at Rutgers (and later at Ohio State University) published a paper about the development sequence of small groups which is now the most quoted and accepted model of the process of team development. He described four basic stages of team development as Forming, Storming, Norming, and Performing. Figure 1 shows these stages as a pyramid with the top representing those teams which have obtained a high-level of performance. The idea is that all teams must go through these four stages to achieve peak performance.
**Forming:**
The forming stage begins when the team is first gets together. For you this was when you first met to discuss writing your Sponsor Introduction Letter. The length of time of this stage depends on many factors including the number of team members and the amount of time spent together. This is considered by some as the most critical phase. This is when you can build foundations of trust among your team members by learning about each other. This time also sets expectations among team members for success and behavior. The forming stage is usually an upbeat, happy time where team members are polite and responsive. Team members will usually have feelings of optimism for the outcome of the project. Also there is usually no real progress made towards completing the task. The real work is forming the team. This is the ideal time in a design project for working on the problem definition, the scope and developing the detailed engineering specification.

**Storming:**
This second phase of team development is the most difficult. It is characterized by conflicts among team members and confusion about team roles. Team members recognize that progress towards solving the problem at hand must be made, but there is not yet an established structure within the team to move forward, reach consensus and make decisions. There can be power struggles at this time if multiple people vie to be team leaders and are not willing to share responsibility. Often, individuals will blame the “concept” of having a team for their problems. Some feelings associated with this stage include defensiveness, competitiveness, tension and jealousy. Team members’ attitudes about the potential success of the project might swing wildly. Some typical behaviors at this stage include not completing tasks, excessive arguing about small points, choosing sides, establishing unrealistic goals and questioning the wisdom of having a team at all. Like the forming stage, little progress towards the completion of the design task is expected or possible at this stage. Real progress won’t kick in until the Norming stage. Also real understanding of the diversity of your team members will begin.

**Norming:**
During the Norming stage, the team members begin to agree on the structure of the team. You decide who will take what roles and how you will conduct “business.” The team will start making progress on their task, but will often bounce back and forth between “Storming” and Norming. This process does not happen all at once. Communication among team members will improve during this phase. Some feelings associated with this phase include an increasing optimism about the team’s chance of success, a growing sense of team unity, acceptance of the team’s individual diversity and a growing sense of harmony.

**Performing:**
This is the highest stage of team development and is characterized by a well-functioning team capable of completing the assigned task. At this point the team is primarily self-directed, needed little input from an outside manager. Roles are clearly defined and tasks are regularly completed on time as promised. This team will be able to tackle almost any similar problem assuming they have the correct technical background. Feelings associated with this phase include pride both in the task progress as well as the team process. Team members respond positively to constructive criticism from their teammates and personal growth can be achieved. This is when the bulk of high-quality work will get done.

4.2.3 Establishing Team Norms/Effective Team Meetings
At the early stages in team development, a team must establish the ground rules for meetings. These include what kind of behavior is acceptable and how the interaction will occur. Although many
individuals prefer “loose” arrangements, some formal rules for meetings should be put in place if you want to become a high performing team. Some other hints that you need ground rules (suggested by Levi) include:

- Topics are avoided repeatedly.
- Irrelevant conversations keep reoccurring.
- Team members do not acknowledge or follow the norms.
- There is conflict over the meaning of norms.
- A meeting leader cannot get members to comply.

Scholtes suggest the following list of options for ground rules for team meetings:

- **Meetings** - When do they occur? How often? How long?
- **Attendance** - When is missing a meeting okay. How are missing members informed about decisions or task assignments? How will you handle excessive absence by team members?
- **Promptness** - What do you mean by on time? How is it enforced?
- **Participation** - How to ensure that everyone gets their say?
- **Conversational Courtesies** - Raise hand to talk? Don’t interrupt? Listen? Respect?
- **Assignments** - How do you make sure tasks are completed on time? How do you know who does what and when?
- **Roles** - Who will fill various roles? How should they be selected? How can they change?
- **Agendas and Minutes** - Who is responsible? What is the format?
- **Decisions** - What represents consensus? How is it attained? Do you vote? Is there veto power?

### 4.2.4 Team Roles

The primary reason for engineers to be included on design teams is their technical expertise and experience. Beyond that, there are secondary roles that team members must take on for successful teams. The role(s) that each team member takes depends on their individual problem solving style. Based on work by R. M. Belbin, Ullman suggest eight secondary team roles that need to be filled on successful engineering design teams. Usually team members fill more than one role and often multiple team members can fill the same role; however, the roles are consistent with the team member problem solving style preference. The roles are:

- **Coordinator** – This team member is typically mature, confident and trusting. They are good at clarifying goals and promoting effective decision making. This can be a good chairperson for a team.
- **Creator** – This person is imaginative and can solve difficult problems. They can also be impractical, have no regard for established team norms and don’t necessarily like to work with facts.
- **Resource-Investigator** – This team member is usually an extrovert known for their resourcefulness. They excel at finding new opportunities and developing contacts. They can sometimes lose interest when the detail stage is reached.
- **Shaper** – This person may be dynamic, outgoing and assertive. They make things happen by finding a way around obstacles. They can also be impatient with vagueness, but like to make logical and objective decisions.
- **Monitor/Evaluator** – The team member is good at seeing the “big” picture and accurately judging possible outcomes. They may not be inspirational leaders, but they are intelligent and shrewd.
- **Team Worker** – This is a consensus building who is concerned about making the team function in harmony and avoiding conflict. They are typically subjective decision makers.
- **Implementer** – This team member turns ideas into action. They are usually disciplined, reliable and efficient. They can be sometimes construed as resistant to change.
- **Completer/Finisher** – This team member is conscientious and detail-oriented and usually delivers results on time. This people are often reluctant to delegate authority and they worry about progress.

### 4.2.5 Team Decision Making

The decisions your team makes during the problem solving process will mostly decide the quality of your solution. The process that you use to make these decisions will have a great impact on how you feel about your team and the solution. According to Levi, there are generally four approaches to Team Decision Making. They are:

**Consent:** This is the approach to use when the decisions are fairly straightforward or have been effectively already made by the team member best suited to make the decision. The typical approach is to create a Consent List on a meeting agenda. During the meeting, the facilitator asks if anyone has a problem with these items. If there are no objections then the decision has been made. This is an excellent way to avoid wasting time discussing low importance decisions or items that have already been agreed upon by the relevant team members.

**Consultative:** In this method, one team member is given the authority to make the decision (usually due to a particular expertise). This person should elicit advice from team members, but they will make the final decision. It is usually obvious when a team member’s qualifications give them the authority, but it should be stated and made clear to all team members that they will be making the decision.

**Democratic:** This seems like a good method (given the history of the U.S.) but it turns out to be the worst team decision making method. The popular vote always makes winners and losers (sometimes almost ½ of the team!). The losers may be quite unwilling to support and implement the decision after it is made. Although this is a quick and decisive method, it should be avoided except as a last resort.

**Consensus:** This is the best approach for any major team decision and it sometimes requires the most work. The key is to continue discussion until all agree on accepting a decision. This does not mean that it is every team member’s favorite decision, but by acceptance all team member are stating that they are willing to support and implement the decision.

How to achieve Consensus:

Hackett and Martin having the following suggestion on how to reach consensus:

Team facilitators can help to achieve consensus by:

- Giving adequate time to discuss and work through issues.
- View conflict as inevitable and ultimately beneficial.
- Encourage negotiation and collaboration among team members.
- Recognize that giving in on a point is not losing and that gaining a point is not winning.
- Encourage team members not to give in just to avoid conflict.
- Don’t allow coin flipping or voting when differences emerge.
Ways to get unstuck when trying to reach consensus include:

- Agree to not agree and then move on to the issue.
- Change topics, call a recess or decide to decide later.
- Work towards a compromise, knowing it might not be the best decision.
- Ask for outside help and input.
- Use voting only as a last resort.

If team members can say yes to the following statements, then consensus has been achieved:

1) Will you agree this is what the team should do next?
2) Can you go along with this position?
3) Can you support this alternative?

### 4.2.6 Managing Team Processes

#### Communication Skills

The ability to communicate is often agreed as the most important skill for effective teamwork. According to Levi, four important skills include how to ask questions, how to listen, how to give constructive feedback and how to manage feelings.

#### How to ask questions:

In general open ended questions are useful for promoting team discussions while yes/no questions are not. It is often useful to follow up on answers with questions that ask for further explanation. Questions asked to the meeting facilitator should be echoed back to the team for discussion.

Hackett and Martin have proposed a set of rules for asking non-threatening questions:

1) Initially ask each question of the entire team.
2) Pause and allow the team members time to consider the questions.
3) If a team member responds, acknowledge the remark and explore the response further if possible or necessary.
4) If no one responds, either ask a particular person or consider reworking the questions.
5) Avoid biased questions
6) Avoid asking too many yes/no questions
7) Avoid questions that put team members on the defensive

#### Active Listening:

The goal of active listening is to increase communication by giving the speaker feedback in order to clarify and promote further discourse. An active listener should communicate that you want to understand the speaker and their underlying feelings. In active listening, the receiver should paraphrase back to the speaker what they heard as a means of clarifying the message. They should also describe their perception of the speaker’s feelings. In this way the speaker and listener can go back and forth and reach consensus on the meaning. This is a method of avoiding the evaluation of a speaker’s communications which may make them defensive and thus decrease further discussion. Active Listening is also a very effective method for conflict resolution.

#### Providing Constructive Feedback

A hallmark of a high performing team is the ability of the team members to provide and receive constructive feedback. Receiving feedback can sometimes be difficult and providing it can be ineffective. Table 4 provides some guidelines by Scholtes that can be helpful when providing this type of feedback.
Table 4: Constructive Feedback Guidelines (Scholtes)

<table>
<thead>
<tr>
<th>START WITH</th>
<th>EXPLANATION</th>
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<tbody>
<tr>
<td>“WHEN YOU…”</td>
<td>Describes the behavior</td>
</tr>
<tr>
<td>“I FEEL…”</td>
<td>Tells how you are affected</td>
</tr>
<tr>
<td>“BECAUSE I…”</td>
<td>Why you are affected that way</td>
</tr>
</tbody>
</table>

PAUSE FOR DISCUSSION

| “I WOULD LIKE…” | Describe the change you want          |
| “BECAUSE…”      | Why you think it will fix the problem |
| “WHAT DO YOU THINK?” | Listen and discuss                  |

How to Manage Feelings

Emotions can run high during a long term project especially when important decisions are made. This can be especially true during the “Storming” stage of Team development. These emotions can be a source of great strength to the team’s efforts, and it is absolutely critical that these emotions do not become destructive. All team members should learn how to handle emotional interactions between members. Kayser suggests the following:

1) Stay Neutral: Everyone has a right to their own feelings. The team should acknowledge the expression of those feelings.
2) Understand rather than evaluate feelings: Be sensitive to verbal and non-verbal messages. When dealing with emotional issues, be sure to ask questions and seek information to better understand the feelings.
3) Avoid asking team members why they feel a certain way.
4) Process feelings in the group: When the team’s operation is disrupted by emotions, stop and cool down. Then discuss the issues in the whole group.

Conflict Resolution

Conflicts occur for a variety of reasons that are desirable on a design team, especially as they work to solve difficult open-ended problems. Differences in opinions, ways of thinking and different methods of solving problems are some of the main reasons teams are more effective than individuals. Maddux points out that conflict become unhealthy when it is avoided or viewed as a competition. He points out five basic methods that are used to resolve conflict.

1) **Avoidance**: This is the “bury your head in the sand” approach; hoping that the problem will go away. It never does.
2) **Accommodation**: Some team members give up their position just to be agreeable, but this costs the team their input.
3) **Confrontation**: By acting aggressively, some members may “win” a confrontation. This can become more important than making a good decision and leads to isolation and non-participation of the “loser”
4) **Compromise**: This way balances the goals of each team member by having each give a little. Unfortunately the optimal decision is most likely not made.
5) **Collaboration**: The team agrees to solutions to the conflict that satisfy all team members. This requires cooperation and respect and takes the most time, usually with the most satisfying outcome.
Of the above approaches, collaboration usually leads to the best and most creative decisions and should be the preferred method of conflict resolution.

4.2.7 References

- Hackett, D. and Martin, C., Facilitation Skills for Team Leaders.
- Kayser, T., Mining Group Gold
- Maddux, R., Team Building: An Exercise in Leadership
- Scholtes, P., The Team Handbook for Educators.
4.3 Social Styles

4.3.1 Background and Motivation

One of the most important skills that a team can develop is the ability to manage the diversity inherent among its members. This diversity is one of the strengths of using teams to solve complex problems like your design project. Managed properly, the team’s diversity can be leveraged to provide high performance for many of the tasks that need to be completed during the project. Managed improperly, misunderstanding of team diversity can lead to prolonged conflict, team member isolation and poor team performance. The types of diversity that design team members’ exhibit include basic knowledge, skills, attitudes, ability, culture, behaviors, and problem solving and working styles. This document provides a framework for addressing team member’s behaviors and how they are affected by Social Styles.

4.3.2 Social Styles

The social style model was originally developed by Dr. James Taylor who was a staff Psychologist at Martin (later Martin-Marietta) Corporation. It was based on earlier work by Dr. David Merrill and Roger Reed who were trying to understand how to predict individual success in business careers based on personality. The Social Style Model™ is now trademarked and owned by the TRACOM group which is a business consulting firm that helps companies get the most from their organizations. For our purposes, we are going to use the model to provide a framework for understanding team members behaviors based on their perceived social style.

The social style model is based on three main measures of human behavior: Assertiveness, Responsiveness and Versatility.

Assertiveness is the degree to which one tends to Ask or the opposite, Tell during interactions with teammates. For example would you ask, “Should we sit down and do the analysis of this system?” or would you pronounce, “Let’s draw the Free Body Diagram now!” Obviously this is a gray area and you probably might fall in between the two opposite. You may even switch between on or the other depending on the situation. Assertiveness can also be thought of as the degree to which others see you as trying to influence their ideas.

Responsiveness is the tendency that you emote or control your feelings. In social situations it is a measure of how you openly display or hide feelings or emotions. An Expressive behavior is marked by open displays or feelings while Controlled behavior is marked by mild or no open displays of emotion. These two measures, Assertiveness and Responsiveness can be plotted on orthogonal axes which divide a plane into four quadrants. Each quadrant as depicted on the next page represents a Social Style. They are:

- **Driving** (Telling and Controlled): A team member with this social style is perceived as independent, practical, decisive, and one who values actions and results.
- **Analytical** (Asking and Controlled): A team member with this social style is perceived as serious, orderly, and logical and one who values facts and accuracy.
- **Amiable** (Asking and Expressive): A team member with this social style is perceived as dependable, open and supportive and one who values security and relationships.
- **Expressive** (Telling and Expressive): A team member with this social style is perceived as ambitious, enthusiastic and stimulating and one who values approval and spontaneity.
Versatility, the third measure, is the ability to adjust individual behavior in a given situation to maximize team productivity. For example your dominant social style might be Driving Behavior. If you have high Versatility, you may behave in an Amiable manner if it most benefits your team performance. Being versatile is not “changing” who you are; rather it is adjusting your behavior to meet the team’s needs to maximize performance. It is important to note that there is nothing inherently good or bad about your social style. Also note that it is how you are perceived, not how you are or think you are. It turns out that individuals who measure themselves are usually wrong 50% of the time, yet when assessed by others their social style is consistently identified. Keep in mind that these are not absolute measures.

4.3.3 Managing your Team’s Diverse Social Style
The most important aspect of managing your team’s social style diversity is basic understanding of your teammate’s behaviors and how your own behaviors are perceived. Then you can use your own versatility to adjust your behavior in certain situations in order to maximize team performance. Your adjustments based on understanding the social styles of your teammates can improve communication, trust, reduce conflict and ultimately increase your team’s performance.

4.3.4 References

- Sullivan, J., Personal Correspondence, ASEE Annual Conference, Honolulu, HI, June 2007
4.4 **QFD: Quality Function Deployment**

4.4.1 **Background**

One of the first and most critical tasks in developing a product is understanding the problem. Individuals and companies large and small have been known to spend incredible amounts of time and money, solving the wrong problem and developing products or devices that do not satisfy the original need. This usually results in product development delays once functioning prototypes are built and it becomes obvious that they do not solve the intended problem. These types of delays are very costly to companies and often result in a huge competitive disadvantage. The best way to avoid solving the “wrong” problem is to work hard at defining the “right” problem. For an engineer, the problem is best defined in terms of a specification where actual measures can be used to determine whether a design has met an intended need. This is no easy task and probably you are starting to appreciate the difficulty in defining in engineering terms such ambiguous ideas of “looks good,” “is safe” or “the best.” One method to translate these ambiguous customer requirements into effective, measurable engineering specifications is Quality Function Deployment (QFD).

QFD was developed in the 1970s in Japan as part of a nationwide effort to improve the countries industrial competitiveness. It was so successful that companies in the U.S. started adopting the method in the 1980s. The American Supplier Institute in Michigan has been a strong proponent of its use in the U.S. auto industry. It has now been established as a proven design technique to assist in specification development and is taught formally to about 2/3 of graduating undergraduate engineers. By adopting this method Toyota Motor Company was able to lower the costs of bringing a new car to market by 60% and to decrease the time required by 1/3. Surveys of mid to large U.S. companies show that about 70-80% use the method and 83% of those feel that the method increases customer satisfaction with their products.

The QFD method is time intensive. It is reported that Ford Motor Company will spend 3-12 months developing its QFD of a new feature. The basic output of the QFD method is a “House of Quality”. This is a diagram which contains all the information relating customer requirements to engineering specifications along with analysis of how competitors satisfy the customers. The best way to understand the value is to go through the process. You should develop a House of Quality (or QFD Table) for your design project and revisit it several times before you make a final conceptual decision for your design project.

4.4.2 **Steps for the Method**

Figure 20 shows a blank House of Quality worksheet (note this excel file is available on PolyLearn for your use). There are seven basic steps to filling this table and capturing what is referred to as the “Voice of the Customer” in appropriate engineering requirements (a.k.a. specifications)
### Figure 20: QFD House of Quality (blank)

<table>
<thead>
<tr>
<th>Customer Requirements (Step #1)</th>
<th>Engineering Requirements (HOWS)</th>
<th>Benchmarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Your Project Name Here</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Units**
  - Targets
  - Benchmark #1
  - Benchmark #2

- **Symbols**
  - • = 9 Strong Correlation
  - ○ = 3 Medium Correlation
  - △ = 1 Small Correlation
  - Blank = No Correlation
**Step 1 – Identify the Customers (Who)**

In consumer product development, it is easy to see that the end-user of a product is a customer; however, they are not the only customer that a designer must consider while developing a product. Manufacturing, Marketing and Sales, and Service may also be important “customers” of a design. If the artifact that is going to be created is a device to increase manufacturing productivity, than the workers who will interface with the device directly might be considered the customers. For your project you must consider all the customers who need to be satisfied by your project, but you can focus on your sponsor. Often times QFD tables will have multiple columns input in Step #3 indicating the relative importance of a requirement for the different customers.

**Step 2 – Determine the Customer Wants/Needs (Whats)**

Different customers want different things in a design. A customer need or want is a statement of “what” the customer wants, usually in their own words. For example, a consumer might want a product that works well, looks good, lasts a long time and is inexpensive. A manufacturing customer might want something easy to make out of easy to obtain materials and standard parts. A marketing and sales person might want something attractive, reasonably priced and easy to display. There are many techniques to get these needs/wants, but the basic idea is to listen to your customers. It is best to get them in the same room. Surveys are also a great tool. For your projects you will be asking questions of your sponsors and you may add some customer needs/wants of your own as you will in some respects act as the manufacturing customer of your project. Figure 21 lists common customer needs & wants. You can use this to make sure you haven’t overlooked any key areas.

Once the customer requirements are determined they can be filled into the House of Quality and grouped by Category

**Step 3 – Weighting the Customer Requirements (Who vs. What)**

Not all customer requirements are created equal. Some are more important to customers than others. Some are absolutely essential. In this step of the QFD process we will mark any must-have customer requirement with an *. One could use surveys and historical data to weight the customer requirements. Another method that we will use is to do pair wise comparison of each customer requirements asking which is more important, adding up how many times each requirement is more important than the others. Once these sums are made, they are scaled so that the sum total equals 100. Often times QFD users make separate weighting columns for each customer so that it becomes clear which requirements are most important to which customer.
Step 4 – Benchmarking the Competition

In the columns of step 4, include the nearest competitors to your project. In many cases there is no competitor, but it is still important to compare against alternatives. The current state of affairs (no new product) might be considered as an alternative. Next mark in the column how well each competitor device satisfies the customer requirements using the following scale:

1 = Design does not meet the requirement at all
2 = Design slightly meets the requirement
3 = Design somewhat meets the requirement
4 = Design mostly meets the requirement
5 = Design Fully meets the requirement

This step will indicate possibilities for competitive advantage and product improvement. It also will show what requirements the competition meets well. You should investigate how your competitor is doing that.
Remember that most “design” is redesign of existing concepts. The best way to get this data is to use “focus groups of users” who can rate the competition. We don’t have this luxury although in some cases we can consult with our sponsor or other users of the benchmarked products.

**Step 5 – Filling in the Engineering Specifications (Hows)**

Hopefully you have already generated a list of specifications. It probably is not yet complete. Remember from last week that these specifications must be measurable and verifiable. A way to get further specifications is to look down your customer needs/wants and determine how you can measure some aspect of each requirement. It is very common to have multiple specifications for each customer need or want.

**Step 6 – Relating Customer Needs/Wants to Engineering Specifications (Hows vs. Whats)**

This step involves determining the relationship between each customer need/want and each specification. The intersecting cell in the house of quality is filled in depending on the strength of that relationship. You can either use symbols or numbers, although the symbols make for a better visual correlation of the strength of relationship. The symbols (or values) to use are:

- ● = 9 Strong Relation
- ○ = 3 Medium Relation
- ∆ = 1 Weak Relation
- Blank – no Relation

This process should be done as a team and will likely lead to many detailed discussions since there is an element of uncertainty here. For a complicated system, filling out this portion of the House can take months!

**Step 7 – Setting Engineering Targets (How Much)**

This gets at answering the question of how good is good enough. These are the numbers and units of the Engineering Specifications. They must be derived using input from the customer, basic engineering knowledge and by comparing to any competition. There is also space in the section of the table to include any known specifications of your benchmarked competition.

4.4.3 Analyzing the Results

There is huge value in setting up a QFD table due to the discussion by your team about the problem. Note that there is nothing in the table about solving the problem, only defining it. You should always make sure that customer requirements are strongly addressed by one or more engineering specifications. If not (a blank row or a row with only triangles), then you are missing specifications and have not yet fully defined the problem. If you have specifications with no related customer requirements (blank columns or columns with only triangles) then you may be over specifying your problem or you don’t know what your customer wants. You should always be concerned whether your target values are different from your competition, especially if customers are satisfied with your competition. It might mean you are solving the wrong problem! Lastly this is considered a working document and will need to be updated as you learn more about your customer and the problem you are trying to solve. There should be discussion in the specification development portion of your SOW about what you learned from employing the QFD process.
4.4.4 References

4.5 **Design Thinking and Creative Techniques**

4.5.1 **Background and Motivation**

Engineers are often called upon to develop innovative solutions to unique technical problems. Engineering is an applied science and combines elements of both Art and Science. One of the skill sets of successful engineers is their ability to solve problems not only with applied technology but with their creativity. With the current “Global” economy, U.S. businesses have been pushing innovation in attempt to have a competitive advantage over lower production cost competition. The idea is that new technology and new innovation are the hallmarks of future successful enterprises in the U.S. This document is a summary of the most well-known and generally useful creative techniques for the design process that have been proven effective for engineers in both industry and in applied research. This document closely follows notes developed by Dr. Bernard Roth of Stanford University. He describes creativity as “… a mental process that can aid in the recognition of a problem, and can motivate the person to formulate an imaginative solutions, which are both valuable and innovative.”

4.5.2 **Creativity in the Design Process**

Phase 2 of Ullman’s general design process is titled “Conceptual Design.” At this stage the goal is to generate concepts that will solve the fully defined design problem. Note it is generally not useful to begin an earnest effort of generating concepts until the problem is fully defined. This may lead to wasted effort or worse yet, development of solutions that do not meet customer needs. The conceptual design phase is the prime time to apply formal creative techniques to generate as many concepts as possible to solve a design problem. That stated, the techniques described here are applicable to all stages of the design process and anytime problems that need solutions arise.

4.5.3 **The Creative Person**

Often “creativity” is associated with “genius.” For example it seems to be universally agreed that Albert Einstein was a creative genius. Many associate creativity with some type of high level of intellectual or artistic functioning. In practice, however, this seems not to be the case. According to Dr. Roth, “All persons of normal intelligence possess some ability to think creatively and to engage themselves in imaginative and innovative efforts.” Not only that, but it is possible to improve one’s ability to think creatively. Furthermore, creativity is not necessarily associated with high levels of intellectual ability. Studies have shown that over 70% of the most creative students do not rank in the upper 20% of their class in traditional IQ measures. Given that all college engineering students are of normal intelligence and know how to learn, it is proper to assume that they can all become more creative through study and practice. This is indeed the case if they are motivated. Motivation to use creativity can take many forms including the most basic to human existence. These might include the need for food and preservation, faith, love, aspirations for fame, fortune or freedom, competition, pride and loyalty. Personal feelings derived for the creative process include pleasure, frustration, exhilaration, fear and satisfaction and pride when a creative task is complete.

The following is a list of attributes that are associated with a creative person. Your further development of any and all of these characteristics will improve your ability for better and more creative problem solving.

- Intellectual Curiosity
- Sensitivity to existing problems
- Acute powers of observation
- Directed imagination
• Initiative
• Ability to think in analogies and images
• Originality
• Intuition
• Memory
• Good verbal articulation
• Ability to analyze
• Ability to synthesize
• Patience
• Determination
• Persistence
• Intellectual integrity
• Good understanding of the creative process

The above list describes human attributes that stimulate creativity. There are many conditions that do the opposite and depress creativity. These will be described next.

4.5.4 Creative Blocks

Adams in his seminal work, “Conceptual Blockbusting” identified major blocks or obstacles to creative thinking and provides methods for overcoming them. The blocks are mental processes that act as a wall to prevent us from correctly understanding a problem or conceiving a solution. Others have identified further blocks so our list is not exhaustive. You can note as you read the list that the “peak” of creative energy for most humans occurs during their childhood where imagination can rule our experience. As we get older, our creative ability is usually eroded due to social pressures and lack of use. It is easy to see how these blocks may have been put in place to allow us to function in our everyday lives. It is equally important to know how to overcome these obstacles when solving design problems. The following gives a general overview of the most common conceptual blocks.

Perceptual Blocks: These are blocks that occur when first encountering a problem that prevents the engineer from correctly perceiving the problem. They include:
• Difficulty in isolating the problem
• Tendency to look at the problem to closely or narrowly
• The inability to view the problem from various viewpoints
• Stereotyped Seeing, “seeing what you expect to see” and premature labeling
• Saturation: The inability to process all problem information.
• Failure to use all sensory inputs.

Emotional Blocks: These blocks tend to color, shade, or limit how we see a problem and we think about it. They include
• A lack of challenge or the problem fails to interest
• Excessive zeal or over motivation to succeed quickly which usually results in going in one direction from the outset
• Fear of making a mistake, of failing, or of taking a risk
• The inability to tolerate ambiguity, or an overriding desire for security
• Preference to judge ideas rather than generate them
• The inability to relax and incubate, i.e. no patience for the creative process to work.
Cultural Blocks: These blocks are acquired by your exposure to a given set of cultural patterns in which you were raised and live. They include:

- The idea that fantasy and reflection are a waste of time and form of laziness. They may even be thought of as a sign of mental instability!
- The idea that playfulness is only for children
- Reason, logic, numbers, utility and practicality are good and that intuition, qualitative judgments, and pleasure are bad.
- Traditional is preferable to change
- Any problem can be solved by science and money
- Taboos: Things that are considered forbidden or profane.

Environmental Blocks: These blocks are imposed by your immediate social and physical surroundings. They might include:

- Lack of cooperation and trust on your team
- Presence of an autocratic boss
- Job insecurity, unwilling to risk
- Distractions, i.e. mobile phones, room mates, etc.
- Lack of support to bring ideas into action

Imagination Blocks: These are blocks that interfere with the freedom with which we explore and manipulate ideas. Other than the first in the list below, most college students do not experience these blocks. They include:

- Fear of the unconscious
- Lack of access to imagination
- Lack of control of imagination
- The inability to distinguish reality from fantasy.

Intellectual Blocks: These blocks usually occur when information is collected or interpreted incorrectly. Much of your undergraduate engineering education has been focused on preventing these blocks from occurring. Some examples are:

- Incorrect information
- Missing information
- Inflexible or inadequate use of the intellectual problem-solving strategies
- Formulation of problems in the incorrect format or “language” (i.e. verbal, math or visual)

Expressive Blocks: These restrict conceptualization at the final stage of idea-expression and communication.

- Inadequate or imprecise language skills to express an idea (language includes verbal, visual, mathematical, musical, etc.).
- Slowness in expression that results in the inability to record ideas quickly enough
- In mechanical engineering, often time the inability to draw out ideas on paper can limit your expression.
4.5.5 The Creative Problem Solving Process

Like the overall design process, there is a generally agreed upon process that most individuals use (some consciously, but most unconsciously). This process involves five major steps:

- **Preparation**: This is the problem formulation phase and involves gathering information and skills needed to work on a creative solution. Note the strong parallel to what is required in your Statement of Work.
- **Concentrated Effort** (“Perspiration”): As Tomas Edison says, Creative “Genius is 1% inspiration and 99% perspiration.” This is a period of intense hard work and can be characterized by lots of frustration. There are many techniques that can be learned to increase the productivity of this phase which are outlined in the next section.
- **Withdrawal** (“Incubation”): This is a period where the conscious mind stops working on a problem and the subconscious takes over.
- **Insight** (“Illumination”): This is that magic “ah ha” moment when the light bulb goes on as the solution appears to the conscious mind. Make sure you are ready to document it!
- **Follow-Through**: The creative process is complete and accomplishes nothing if there is no follow through on the idea including implementation.

Although in the best of all worlds, this would be a linear process with a fixed amount of time dedicated to each step with guaranteed results; none is true. Like the design process, it is not linear and iteration is again an important characteristic. Also the withdrawal (“incubation”) phase may take some time. There are many documented magical moments of insight during times of idle thought. These famous situations were always preceded by preparation and concentrated effort!

4.5.6 Techniques to Improve Creativity

The following described techniques are well-documented and recommended to improve the Concentrated Effort phase of the creative problem solving process. They are named separately, but combining them is often desirable. They include:

- Set-Breaking
- Brainstorming
- Inversion
- Analogy
- Empathy
- Fantasy
- Check Lists
- Attribute Listings
- Morphological Analysis

**Set-Breaking**: A “Set” is a word used by psychologists to mean a predisposition to or a particular method or way of thought in solving a problem. It is also sometimes referred to as a “schemata.” A person who is “in a rut” connotes set. Being aware of a set is not easy and being aware that a set might be limiting your problem solving creativity is even harder. To become aware of a set, one can use a “set-breaking” experience. This means forcing yourself to let go of your conventional ways of thinking. One technique is to imagine that you are trying to solve the same problem in a whole new environment. For example your user is in the Arctic, not California or maybe they live on another planet where gravity is reversed and the inhabitants are handless and have no vision. In this imaginary world, your set will not work, forcing you...
outside it to look for solutions. When you return from this imaginary environment you may have lost some of your set.

**Brainstorming:** This is clearly the most used and trusted idea generating technique. It can help remove obstacles of creativity that are caused by fear of criticism or fear of appearing foolish. The basic idea is to generate as many ideas as possible by avoiding all judgment during the process. There are basic rules that should be followed:

- Someone must keep a record of all ideas for all to see
- No Criticism or Judgment (good or bad) is allowed.
- Go for quantity and always say the first thing that comes to your head.
- Think as wild as possible and use humor.

A brainstorming session is over when you will have a long list of ideas that have spawned new ideas. If done correctly, you will be exhausted at the end of the session and should wait until a later date for evaluation and further elaboration.

**Inversion:** This is set-breaking technique which calls for looking at problems from new vantage points. Osborn suggests a checklist to consciously set-break by asking the following questions to ask of your problem.

- Could a solution be put to other uses? Are there other ways to use it or new ways if it was modified?
- Can you adapt another idea? Do similar things exits. What ideas do similar things suggest? Are there parallels?
- Can something be modified? Is there a new twist, color, motion, sound, odor, form, shape or any other change?
- Can ideas be magnified? What can you add, more time, more frequency, stronger, higher, longer, more value?
- Can an idea be minified? What can be subtracted, made smaller, condensed, miniaturize, lower, shorter or lighter?
- What can be substituted? Who else instead? What else instead? Other ingredients, other materials, other part, other power, other place, other approach, other process?
- What can be rearranged? Can components be interchanged? Other patterns, other layouts, other order, switch cause and effect, difference speed, different schedule?
- What can be reversed? Can positive and negative be switched? Can it be turned around,
- What can be combined? Can there be a blend? Alloys? Assortments, Combine purposes? Combine ideas? Combine appeal?

**Analogy:** This method uses similar situations in other problems to stimulate new ideas. Analogies may come from other engineering solutions, or from nature, or even from literature non-technical areas. This can be done by individuals and is also useful for groups.

Examples:

- Could you design airplanes that fly like birds?
- Can you make tunnel digging machines that dig like worms?
- Can you make landing gear for an airplane that stows like birds feet?
- The original cars were built like horse-drawn carriages.
**Empathy:** This method involves identifying personally with the thing, part of process being devised. The object is to become the part that is the solution to a problem and see the problem from that position. A famous example is provided by an engineer who was tasked to remove walnut meat (whole) from a shell. By imagining himself as the meat, trying to get out of the shell by pushing, the engineer realized that internal pressure could remove the shell. He then devised a system of drilling a hole in the shell and pressurizing the shell to remove it, thus leaving the meat intact. This is an extremely useful method which requires the willingness to play act. This may require overcoming some inhibitions.

**Fantasy:** Closely related to empathy, this technique requires directed daydreaming. Forget about the rules of nature and let your mind go in any direction your imagination takes you. Easy to do as individual, but can also be done in groups.

**Check Lists:** General listings are useful during early idea development to avoid the omission of important features or customer requirements. They can also suggest possible improvements. The type of list is dependent on the particular product being developed. New ideas should be added as they occur for later use. When making lists you should keep an open mind for new ideas inspired by associations. Check lists should contain the following information:

- **Physical Conditions** including: size, weight, shapes, taste, color, finish, pressure, temperature, vibration, shock acceleration, noise, radiation, etc.
- **Functional Aspects** including materials, production processes, applications, packaging, etc.
- **Attributes and unusual characteristics** of shape, finish details, package, energy sources, appearance, feel, fashions, maintenance features, assembly methods, etc.
- **Social Aspects** including timing, human compatibility, degree of complexity, serviceability, cost, production potential, effect on living conditions, etc.

Look for possible rearrangements, recombination, modifications and elimination of excessive details, features or waste.

**Attribute Listings:** this technique involves the list of attributes of various objects, or the specifications or limitations of certain need areas. After completing the list attributes or specifications can be modified allowing originally unrelated objects to be brought together to form new combinations that might better satisfy needs. For example an old fashioned wooden-handled screw driver has attributes such as:

1) Round, steel shank
2) Wooden handle attached by a rivet
3) Wedge-shaped end for engaging a slot in a screw
4) Manually operated
5) Torque provided by twisting action

All of these attributes have been changed to improve the screw driver:

- Round shank – hex shank (can add a wrench for increased torque)
- Wooden handles – molded plastic handle (less expensive, more durable)
- Wedge shape – various interchangeable shapes for different screw heads
  - Manual Power – Electric battery or pneumatic available
- Twisting action – “Yankee” type with pushing action

**Morphological Analysis:** This is a programmable method of using the attribute listing to make new combinations. The method involves breaking the problem into two or more dimensions, attributes or subsystems based on the functional requirements. Each attribute is brainstormed to generate a long list of
possible ways of meeting the requirement. This list is then placed in an orthogonal matrix and then a new idea is generated by forming every possible combination and evaluation the feasibility of the combination. An example from Adams book is shown below for a new personal transportation device where the three dimensions are power, seating and operational media. Each cube represents a possible combination of the three dimensions for consideration.

![Example Morphological Cube](image)

Figure 22: Example Morphological Cube

4.5.7 Last Thoughts on Creativity:
When working at being creative there are two major points to keep in mind:
1) Everyone can be creative
2) Everyone has some blocks that limit them

By working at the skills and being aware of the cause of your own blocks you can begin to fully tap your creative potential and improve it for the remainder of your life!

4.5.8 References
- Roth, B., *Notes on Creativity*, ME112 Stanford University, 1994