Biomedical Engineering Department

Senior Project Guide

2018/19

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INTRODUCTION – 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.

The Senior Design Project is a 2-quarter, team-based experience where students design, build and test a solution to an externally supplied problem. This format allows students to develop teamwork and communication skills needed for today's workplace, as well as gain valuable experience working with industry partners.

The senior project sequence is offered Fall/Winter and Winter/Spring quarters. Student teams are formed in the beginning of the first quarter and stay together for the entire project. The first quarter students conceptualize, perform feasibility studies and ultimately decide on a design direction. It culminates in a formal Concept Design Review and design freeze. During the second quarter, students complete the detailed design, hold a Preliminary Prototype Review, get the sponsor's approval to build, and start building their prototype. They complete the build and test the prototype. A Final Report and Design Exposition poster are presented at the end of the course sequence. Throughout the project each student team has an industry/faculty sponsor who meets with them on a weekly basis guiding them on their project and providing technical feedback.

Throughout these two quarters, the BMED 455/456 instructors 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! Good luck as you embark on a journey of learning, discovery, hard work, and hopefully great personal satisfaction for your completed project!

COURSE OBJECTIVES

- Apply a formal engineering design process to solve an open-ended, externally supplied engineering design problem.
- Work effectively on an engineering team.
- Develop, analyze, and maintain an engineering project schedule using a PERT chart and appropriate software. Identify the project critical path.
- Use Quality Function Deployment (QFD) to evaluate customer requirements.
- Formally define an engineering problem.
- Generate an engineering specification document.
- Apply creative techniques to generate conceptual design solutions.
- Apply structured decision schemes to select appropriate engineering concepts in a team environment.
- Design systems within constraints (strength, size, materials, performance, cyclic loads, etc.).
- Evaluate potential design solutions through the use of engineering and physical science analysis techniques and tools.

- Apply current industrial design practice and techniques such as DFX, FMEA and/or TQM to engineering design problems.
- Construct and test prototype designs.
- Develop and implement a Design Verification Plan and Report.
- Communicate and present engineering design project results orally, graphically, and in writing.
- Discuss and take a stand on open-ended topics involving engineering ethics and product liability.
- Discuss engineering professionalism and its responsibility to society.
- Understand the codes of ethics and their implications in engineering practice.

Grading and Assessment

All students, regardless of lab advisor, 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 project 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. notebook) throughout the courses. Consult the course syllabus and your project 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 available section with a new project and a new team. This may delay graduation by up to a full year.

Student, Advisor, 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, project advisor, and course organizer are available to provide technical and management assistance and to help you keep your project on schedule.

Student Design Team Responsibilities:

- 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 Notebook (recommended on a daily basis)
- Prepare and present Stage Gate Reviews in class and to the sponsor.
- Prepare and present a Final Prototype Review in class and to the sponsor.
- Procure materials, fabricate, build, and/or supervise construction of a prototype
- Establish a test plan, procure diagnostic equipment, and perform testing
- Present final prototype and poster at Project Expo

- Document entire process in a Final Prototype Review Report
- Complete Senior Survey
- Meet additional course requirements outlined on syllabus
- Complete all required forms for purchasing and traveling
- Interact with faculty advisor (in lab as stipulated on the syllabus)
- Interface regularly with sponsor (weekly)

Project Advisor (Laboratory Instructor):

- Work with team to define an appropriate project scope
- Coordinate lab activities and presentations
- Assist with sponsor-team interactions
- Evaluate all team assignments and assign course grades
- 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

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 final 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 final prototype at Project Expo

Project Support Coordinator:

- 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 Survey

Travel Policies and Required Forms

By its nature, Senior Design Project may involve some travel to visit your sponsor or interact with end users. Teams should work in conjunction with their sponsor to develop a travel budget that cannot be exceeded for the two quarters and are responsible for maintaining that budget.

All information concerning travel is available at this website:

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.

Purchasing and Reimbursements

You or your sponsor will need to procure parts and materials for your prototype. All purchases should be discussed and approved by your project 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:

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

For delivery of all equipment and components, use this address:
Dr. Christopher Heylman or Dr. Michael Whitt
California Polytechnic State University
c/o Department of Biomedical Engineering 13-260
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.

Project Materials & Travel Budget

Whether or not you directly purchase materials for your prototype, your team must create and maintain a Materials & Travel Budget for your project. This document (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 the prototype and testing. All budget details (prices and sources for all purchased components including tax and shipping) 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.

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 project 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 project advisor for review.

AGAIN, DO NOT SIGN ANY AGREEMENT PROVIDED BY YOUR SPONSOR!

Many sponsors have agreed to use a standard Cal Poly Class Project Sponsorship Agreement. For these projects, you will be asked to sign a Cal Poly Project Confidentiality and Intellectual Property Agreement. Your project advisor will provide you with a copy to sign.

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.

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 prototype in a safe manner
- Test your prototype 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 40 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!

You will "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.

At a minimum you should use the following guidelines as you evaluate your design (Dieter and Schmidt):

- Recognize and identify the actual or potential hazards, and then design the product so they will not affect its functioning.
- Thoroughly test prototypes of the product to reveal any hazards overlooked in the initial design.
- Design the product so it is easier to use safely than unsafely.
- If field experience turns up a safety problem, determine the root cause and redesign to eliminate the hazard.
- 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.
- 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.
- Minimize the use of flammable materials, including packaging
- 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.
- Think about the need for repair, service, or maintenance. Provide adequate access without pinch or puncture hazards to the repairer.
- Electrical products should be properly grounded. Provide electrical interlocks so that high-voltage circuits will not be energized unless a guard is in place

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 the class 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, 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 Preliminary Design Review/Design Freeze (PDR). The PDR takes place in the middle of the class.

After the PDR, you'll continue and 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.

Senior Project Safety Timeline

BMED 455 (1st quarter)

- Week 2 – Review and sign the Senior Project Safe Practice Procedures
- Week 2 – Create an FMEA for your concept design.
- Week 8 – Midpoint Project Report – include a Design Hazard Checklist

BMED 456 (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.
- 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 and 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 prototype.
    - Important: Do NOT work on your senior project hardware at home!

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 project 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/

Senior Project Safe Practice Procedures

1. Read the course Senior Project Safety Section of the Success Guide.
2. Do not do any Senior Project hardware development (i.e. manufacturing or testing) outside a Cal Poly facility without the authorization for your senior project advisor.

3. All hardware testing must follow written testing procedures reviewed by your advisor or the department safety coordinator.
4. When working on your senior project in a Cal Poly facility, you must follow all of those facilities Safety Procedures.
5. Use proper Personal Protective Equipment (safety glasses or goggles, ear plugs, gloves etc.) when operating laboratory equipment or experiments.
6. Wear appropriate attire when operating equipment. Secure long hair around rotating equipment or open heat source, proper shoes where drop hazards exist, etc.
7. No equipment shall be operated without the instructor's permission.
8. No unsupervised use of laboratories without prior written authorization by the instructor.
9. No working alone in the laboratories.
10. Any accident or illness must be immediately reported to the instructor and/or the Biomedical Engineering Department office.
11. Any unsafe or hazardous condition in lab (liquid spills, electrical hazards etc.) must be immediately reported to the instructor.
12. In case of an emergency dial 911 and tell the dispatcher:
    - The nature of the emergency
    - Your name
    - The location of the emergency
13. To evacuate the building in an emergency follow routes posted near the exits of the building.

Design Hazard Checklist

Team: ____ Advisor: ______________________
Y / N

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 sheer 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.

Description of Hazard	**Planned Corrective Action**	**Planned Date**	**Actual**

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 instructors 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. The fixed deliverables are listed in the 455 and 456 syllabi. Any further requirements or deliverables beyond those listed in the syllabi will be announce in class and added to PolyLearn. This section describes the fixed deliverables in detail.

BMED 455 (First Quarter)

- Letter of Introduction to Sponsor
- Indications for Use
- Product Specification Matrix
- Failure Modes and Effects Analysis (FMEA)
- Hazard and Risk Assessment
- Conjoint Analysis
- Design of Experiments
- Scope of Work
- Project Planning Presentation
- Quality Function Deployment (QFD) House of Quality
- Pugh Chart
- Concept Review Presentation
- Midpoint Project Report
- Preliminary Design/Design Freeze Presentation

BMED 456 (Second Quarter)

- Updated project plan
- First draft final report
- Final Test and Manufacturing Plan Presentation
- Preliminary Functional Prototype Presentation
- Final Poster
- Final Report
- Final Design Presentation

See below for detailed information about each of these deliverables.

Design Notebook (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 notebook.
- 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 notebooks so only put notes and observations that you are willing to share.]

Notebook Details

One notebook 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 notebooks).

Additional notebook 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 notebook!
- 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 notebook 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 entries (for a professional consulting engineer, the signed design notebook can become an important piece of legal evidence in patent and product liability disputes). Have entries countersigned by someone who understands your design. This will usually be a teammate or your project advisor.
- Timing: You should be making entries in your notebook 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)

Notebook Assessment

Your notebook 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 notebook and tell what you did and why. Your notebook 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 notebook, pose these questions to yourself:

- If my notebook 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 notebook?

Notebooks will be graded based on tracking of project management information, product development, organization, and personal reflection. Be sure to follow the notebook format specifications given above and in the 'Design Notebook Review Checklist' on PL. 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' notebooks:

- Many students think of the notebook as just notes written for the writer. It is not! The notebook is a dialogue about the project, written in a fashion that is understandable by a third party. Annotate, annotate, annotate. Explain, explain, explain. Read the guidelines above occasionally to remind yourself what should be in the notebook.
- 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 notebook)? 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?

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, Google Docs, or some other method?

Compose an e-mail to your sponsor (with a copy to your project advisor), identifying the team working on the project (with names, phone numbers, and e-mail 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 will also need 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 project 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.

Indications for Use

Your indications for use (IFU) statement outlines what your product does, its intended use, and its intended users. In the world of medical devices, diagnostics, and pharmaceuticals, this statement serves as a 'contract' with the FDA. Everything contained in the IFU needs to be proven with significant confidence to the FDA before they will approve a product for release. Once approved, the device can be marketed only for the function, use, and patient population indicated in your iFU. For example, if your IFU states that a hip implant is suitable for full weight-bearing non-athletic use in patients aged 50-75 weighing less than 300 lbs. in cases of elective, non-diseased total hip replacement, your test plan and clinical trials can clearly identify whether your device meets these criteria by testing a suitable range of patients in this patient population. If you merely claim that your device is for any patient needing a total hip replacement, the lack of age, weight, pathological, and use requirements makes the development of a test plan to prove to the FDA that you device can is safe in efficacious in all cases, becomes very difficult and amorphous. Be detailed and specific, keeping verification and validation in mind as your craft your IFU.

Product Specification Matrix

This matrix will be used to identify your customer requirements and transform them into quantifiable engineering metrics. A specification will be defined for each metric in order to define the design inputs.

The rationale is a justification of the engineering metrics and specifications used to quantitatively define each customer requirement.

Customer Requirement	Engineering Metric	Specification	Rationale
"adjective and adverbs" – in the customers own words, what does the product need to do (i.e the guidewire needs to be easily inserted into a catheter)	Quantitative, measurable parameters that can be tested (i.e. push force, lubricity, tensile strength, elasticity, etc)	Value or range of values that, if met, suitably satisfy the customer requirement (i.e. >10N, or 5N +/- 0.2N)	Explanation and justification of how/why the engineering metric and spec provided are sufficient to meet the customer requirement

Scope of Work (SOW)

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 your project plan, your Midpoint Project 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 format shown below:

- A Title Page showing the project title, sponsor name, and names and email addresses of the persons preparing the Scope of Work.
- An Executive Summary (or Abstract) that gives an overview of the document.
- A brief Introduction that tells the reader what the project is about, who the stakeholders are, and basically describe the goals. It should also briefly describe the other sections of the document.
- A Background should follow and include a discussion of what existing information (from literature, previous work, etc.) will have a bearing on the proposed work. 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)
    - Listing of applicable industry codes, standards, and regulations
- An Objectives section, which sets the scope of your project. This should state precisely what you will do for your sponsor. Include:
    - Problem statement
    - Boundary definition (what the project explicitly includes and what it explicitly does not include)
    - Summarize your customer wants/needs (put full list in Appendix)
    - Product Specifications Matrix
    - Description of how you will measure each specification
    - Discussion of high risk specifications
- A section discussing your Project Management will come next. Include:
    - Description of the overall design process you expect to follow in solving the problem
    - Table of key deliverables and the project timeline
    - Any unique techniques (early prototypes, special analysis or testing, etc.) you plan to use on the project
    - Discussion of the next steps in the process
    - Summary of your Performance Evaluation Review Technique (PERT) chart and critical path
- In your Conclusion, briefly restate the purpose of the document (to get your sponsor's agreement on the project scope) and discuss 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 (OWL) for detailed information on the format of these citations.
- Add Appendices after the final section of the report. These may include a breakdown of design requirements, technical specifications, contacts, etc. Note that everything in the Appendices should be specifically referenced within the body of the report. Appendices should appear in the order they are introduced in the body of the report. Unreferenced material should not be included. Each Appendix should have its own page numbering (e.g. A-1, B-5, etc).

In a commercial Scope of Work there are often other items, such as the qualifications of the proposer(s), a reporting schedule, a cost estimate, and various contractual conditions.

More about the Background Section

The Background section of the Scope of Work is one of the most important sections in your Scope of Work. It serves as an important repository of information about your project. It confirms your diligence in looking for the root cause. It documents alternative solution types (so you don't have to 're-invent the wheel'). It indicates that you know how big of a technical challenge you are undertaking. Include descriptions of the customer, the need, related products, patent search results, and technical background. You may also want to summarize this information in tables.

Students often ask, "How long does my Background need to be?" The answer to this question is, "as long as it needs to be." That's frustrating, but it's also true. The reader needs to be able to read this section and know everything that is important about your design challenge: The user, their need, the constraints, the technical issues, what's been tried before, other possible solutions you've found, etc. As a rule of thumb, the Background should be about half of your total SOW length.

More about the Objectives Section

The objectives and specification part of the Scope of Work is particularly important for senior design projects (really, for all projects). Lots of time and resources are often wasted designing the wrong system or component because it is poorly specified. You should start the section with a brief summary of the customer needs/wants you have identified. To ensure you have considered all important aspects of the design, check the list of types of potential customer needs/wants. You might use the main headings from this example to organize your specification list into logical groupings.

Main headings	Examples
Geometry	Size, height, breadth, length, diameter, space requirement, number, arrangement, connection, extension.
Kinematics	Type of motion, direction of motion, velocity, acceleration.
Forces	Direction of force, magnitude of force, frequency, weight, load, deformation, stiffness, elasticity, intertia forces, resonance.
Energy	Output, efficiency, loss, friction, ventilation, state, pressure, temperature, heating, cooling, supply, storage, capacity, conversion.
Material	Flow and transport of materials. Physical and chemical properties of the initial and final product, auxiliary materials, prescribed materials (food regulations etc).
Signals	Inputs and outputs, form, display, control equipment.
Safety	Direct protection systems, operational and environmental safety.
Ergonomics	Man-machine relationship, type of operation, operating height, clearness of layout, sitting comfort, lighting, shape compatibility.
Production	Factory limitations, maximum possible dimensions, preferred production methods, means of production, achievable quality and tolerances, wastage.
Quality control	Possibilities of testing and measuring, application of special regulations and standards.
Assembly	Special regulations, installation, siting, foundations.
Transport	Limitations due to lifting gear, clearance, means of transport (height and weight), nature and conditions of despatch.
Operation	Quietness, wear, special uses, marketing area, destination (for example, sulphurous atmosphere, tropical conditions).
Maintenance	Servicing intervals (if any), inspection, exchange and repair, painting, cleaning.
Costs	Maximum permissible manufacturing costs, cost of tools, investment and depreciation.
Schedules	End date of development, project planning and control, delivery date.

Your Specifications Table can be developed and documented as follows:

- Use the Quality Function Deployment (QFD) process to link all customer needs/wants to potential methods of assessing your final design (engineering specifications), then establish appropriate target values for each specification. Be sure to describe this process for your sponsor in the text of your report.
- Construct a table of formal Engineering Specifications (see Table 1). This table should include:
    - Description of each parameter (HOW from the QFD)
    - Target value of that parameter (HOW MUCH from the QFD)
    - Tolerance on the target (min, max, or +/- tolerance)
    - Risk you anticipate in meeting that target (how likely you will fail to achieve this goal)

- Compliance method (how you will determine if that goal is met). Common approaches are by Test, Analysis, Inspection, or Similarity to existing design.

- After the Specifications Table, include a more detailed explanation of each parameter and describe how you will measure your designs' success or failure in that area. Spend extra time discussing any high risk parameters. A bulleted list (one bullet for each specification) is a good approach.

Table 1: Example of Engineering Specifications Table

Spec. #	Parameter Description	Requirement or Target (units)	Tolerance	Risk	Compliance
1	Weight	5000 lb.	Max.	H	A, T, S
2	Size (see Figure 1.)	10 in	±0.005	L	I, A
3	Production Cost	$438	Max	M	A
4	Power	10 HP	Min	L	T

Concept Models / Concept Prototypes

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 your Concept Review Presentation.

The Concept Prototype is a more realistic representation of part of your lead concept. It should be at least partially functional so you can discover more about the 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 Preliminary Design/Design Freeze Presentation.

Senior Project Presentations – Overview

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

1. Project Planning Presentation
2. Concept Review Presentation
3. Preliminary Design Review/Design Freeze Presentation
4. Final Test and Manufacturing Plan Presentation
5. Preliminary Functional Prototype Presentation
6. Final Design and Prototype Presentation

In addition, you will present one informal presentation (Preliminary Prototype Plan Presentation) and one poster presentation (Project Expo).

Summary of Presentations

Quarter	Presentation	Summary
1^{st}/455	Project Planning	1^{st} iteration of project plan developed
1^{st}/455	Concept Review	Conceptual ideas (including physical concept models) for product solution are presented
1^{st}/455	Preliminary Design/Design Review	Frontrunner design solution and concept prototype is presented
1^{st}/455	Preliminary Prototype Plan	Early thoughts on plans for next quarter's prototype development
2^{nd}/456	Final Test and Manufacturing Plan	DOE factors and levels, test protocols, and build plan presented
2^{nd}/456	Preliminary Functional Prototype	Up to date progress on prototype
2^{nd}/456	Final Design and Prototype	Final version of prototype presented
2^{nd}/456	Poster Expo	Final version of prototype and poster presentation given to Industrial Advisory Board and broader Cal Poly community

Detailed contents and rubrics for each presentation will be presented in class. 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/.

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.

Important of Preliminary Design/Design Freeze Presentation

In conjunction with your preliminary design/design freeze presentation, you will make a formal presentation to your project sponsor. The goal of this presentation is to obtain your sponsor's approval to begin constructing your prototype. Your presentation should provide sufficient evidence of your design and analysis to convince your sponsor that your solution will work. Complete prototype costs, manufacturing plans, and test plans/costs should also be included in this presentation. Be sure to show a drawing/photos of your Concept Prototype during your presentation, and discuss what you learned from it. This presentation will take place in lab before you deliver it to your sponsor in order to get feedback. Consult with you project advisor for details. If your sponsor requests that you make this presentation in person, please reread the travel policies before making your plans for the review.

Risk Assessment / Safety Review

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.

After your 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 advisor and the technicians.

Ethics Activities

Throughout the project, 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 advisor will provide more details.

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, and 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.

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.

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 2nd quarter, each team will periodically prepare a brief (1 page) status memo that updates your sponsor and your instructors 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 memo can be written as a narrative accompanying these pictures. This is a stand-alone report in senior design. Please be sure to document activities completed, as well as upcoming activities, and activities where you have concerns and/or request assistance or guidance.

To write this report, review your last update 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 project plan (PERT chart) and to highlight activities completed since the last update. 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.

Hardware/Safety Demonstration

The Hardware/Safety Demonstration is scheduled after prototype manufacturing. The goal is to show your advisor and appropriate (mechanical and/or electrical) safety technicians that you have carefully considered the safety hazards of your design and implemented all reasonable precautions to protect yourself and your sponsor. In addition to your final assembled hardware, bring copies of these safety-related documents to the demonstration:

- FMEA
- Safety Hazard Checklist
- Risk assessment
- Test plan
- Individual test procedures (including safety precautions from Risk Assessment)

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

ABET Activities

Senior Design Project fulfills many requirements necessary for the BMED 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. As part of this process, all senior project students must fill out a Senior Survey during BMED 456. This is not graded, but completion of the survey is necessary to receive a grade for the course.

Operators' Manual

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.

Final Prototype

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

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

Final Design Review (FDR) Report Contents

What to turn in (after approved by your advisor):

- One electronic or paper (check with advisor) copy for your project advisor.
- One electronic or bound copy (check with your sponsor) for your sponsor.
- One electronic (pdf) file which you will upload to the library's DigitalCommons website. The library copy should not have the Evaluation and Grade page. Before uploading you must get

your project advisor the receipt and library form where he or she signs to confirm the project meets the course requirements. If you have a proprietary project, please see below. All instructions for uploading the library copy can be found on the Library's website at http://lib.calpoly.edu/help-and-support/seniorprojects/. Please follow the library steps, EXCEPT leave the library form with your project advisor.

Proprietary Work: If your project is proprietary and your sponsor does not want the report available in the library, then submit everything above, with the following modifications:

- Instructor Copy: The only change should be the addition of a Confidentiality Statement just before the Statement of Disclaimer.
- Sponsor Copy: The only change should be the addition of a Confidentiality Statement just before the Statement of Disclaimer.
- Library PDF Upload: For the body of the report, submit only the Title Page and Confidentiality Statement. DO NOT include the abstract, unless your sponsor approves it 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 five 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 Evaluation and Grade Page
- The Title Page
- The Disclaimer Page
- Confidentiality Statement

Each page is labeled in RED.

EVALUATION AND GRADE PAGE (ERASE THESE LINES)

Include this page in project advisor's copy only

Steam Powered Lawn Mower

by

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

Project Advisor: Type Project Advisor's Name Here
Instructor's Comments:

Instructor's Grade: ______________
Date: _________________________

TITLE PAGE (ERASE THIS LINE)

Steam Powered Lawn Mower

by

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

Biomedical Engineering Department
California Polytechnic State University
San Luis Obispo
2018

STATEMENT OF CONFIDENTIALITY, ONLY IF NECESSARY
(ERASE, AND NOTE THAT TEXT BEGINS 1.5 INCHES FROM TOP OF PAGE)

Statement of Confidentiality

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

DISCLAIMER PAGE

(ERASE, AND NOTE THAT TEXT BEGINS 1.5 INCHES FROM TOP OF PAGE)

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.

Project Expo Poster Presentation

The Project Expo is the culminating event of the Biomedical Engineering Department's two-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. The teaching staff, project sponsors, other faculty, and guests will attend this Exposition. Students should feel free to invite their friends and family to the event as well. (In our experience, parents of graduating students love to come see their child's magnum opus.) Teams must have their poster display set up prior to the public event. Please consult your project advisor for the day's schedule. Prior to opening the show to the public, the teaching staff and other faculty will grade each display. All students should leave the venue during this time. During the public portion, each team should plan on having its poster station manned for the entire event by at least one student from the team.

Poster Requirements

Posters should consist of one flat (NOT tri-fold!) 36" x 48" poster mounted on a single sheet of corrugated board in landscape orientation. The bookstore carries corrugated sheet in this size, but you will need to build a support on the back so that the poster will be free-standing on the provided tables.

Your poster should be glued to your corrugated sheet using spray adhesive. Spray the adhesive on a grassy area, so the overspray won't stick on the floor. Make sure the poster sticks well at the edges, and lay it down carefully so you don't end up with any bubbles.
Posters will be graded in two main categories.

- 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 words should be clearly readable from 5-10 feet away.
- 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 display grade will come from your prototype(s). Specifically, graders will assess the quality and completeness of your final prototype.

Laying Out and Printing the Poster

The posters must consist of a single plotted sheet glued to foam board. Students have found that using PowerPoint is effective in creating the layout. You can also use Adobe software and others. Printing can be done using the color plotter in 13-107. Please read the instructions near the plotter for important tips. When plotting out your final copy, we will provide glossy paper. You will need to sign up for a specific time slot in which to print your poster on the glossy paper. The sign-up sheet will be posted on Google drive and announced the week before the Expo.

Poster Do's:

- Do use large font sizes; legible 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.

Poster Don'ts:

- Don't include a background – keep it white so your dark text is readable (and the poster prints fast).
- Don't use any font sizes smaller than 24.
- Don't use a lot of text or full sentence (keep it brief).

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 Requirements

In order to do a final check of your components before you hand them off to your sponsor, safety technicians and project advisors will review your display two hours before the Expo begins. Please make sure you have ALL of the items listed below at your display for this final safety review.

Expo Safety Review Checklist

- Poster
- Final Design Review Report (hardcopy)
- All Project Hardware (prototype & spare parts)
- All Appropriate Safety Labels & Placards Affixed to Prototype
- All Design Hazard Checklists (PDR, CDR, Hardware Safety Review)
- Safety/Operators Manual (extra copy, separate from report)

At the End of the Expo

In addition to being present to show off your work to Expo attendees, you should deliver your final prototype and report to your sponsor at the conclusion of the Expo.

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 project 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:

- Check your report format using the "Senior project information packet" on the library website (http://digitalcommons.calpoly.edu/seniorprojects/).
- Follow the "Detailed guidelines for submitting your senior project" (http://lib.calpoly.edu/help-and-support/seniorprojects/):
    - Complete and print the "Senior project requirement form" on the library website.

- 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."
- Bring the form and attached receipt to your project advisor (not the department office).
- Upload your report to DigitalCommons:
  - 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.
  - 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.

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

Project/Team: ____

X	Task
	Prototype tested to verification plan (attach copy of final report).
	Operators' Manual (& safety precautions) included in Final Report Appendix (advisor to confirm).
	Final hardware and any extra components delivered to Sponsor (attach sponsor email).
	Expo poster delivered to Sponsor (electronic documentation required if e-mailed).
	Final Report delivered to Sponsor (copied to advisor).
	Final FDR Report and Expo Poster uploaded to PolyLearn site (advisor to confirm).
	Final Budget Spreadsheet (with actual costs) emailed to advisor.
	Signed library form and payment receipt delivered to advisor (restricted access if NDA in place).
	Final 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!)
	Fabrication area cleaned up & tools returned to shop.
	Test equipment returned. Electronics Tech Signature: ____________________ Print Name: ____________________

Senior Project Resources

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

Faculty and Staff

https://bmed.calpoly.edu/faculty/
https://bmed.calpoly.edu/students/faculty-advisors/

Labs & Support Facilities

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

LABORATORY	LOCATION
Advanced Instrumentation Facility	-
Biofluidics Lab	ATL, St. Jude Lab
Biomedical Imaging and Bioinstrumentation Laboratory (BIB Lab)	-
Biomedical Materials Characterization (BioMAC) Laboratory	-
Electrophysiology and Neural Electronics Laboratory (ENEL)	-
High Performance Modeling and Simulation Laboratory	41-211
In Vitro Systems Laboratory	41-209
Microcirculation and Vascular Regeneration Laboratory	38-134
St. Jude Bio-Engineering Laboratory	ATL
Tissue Analysis Laboratory	197-209
Tissue Engineering Laboratory	41-209A

Bonderson Student Project Center

The resources of the Bonderson Student Project Center (Building 197) are available to you to complete your senior design project.

- **114 – Mustang ’60 Machine Shop:** This shop is used by all engineering students to build their projects. Student technicians are there to provide a watchful eye and answer any questions.
- **209 – Tissue Analysis Facility:** Provides competencies in the areas of histological evaluation and gene expression.

The center offers senior project team locked storage in three sizes:

- Hallway storage lockers (1x1x2 ft.)
- Outdoor cages (3x4x3 ft.)
- Workbenches/cabinets in dedicated project rooms 108-110 (only for large projects)

Any of the Student Shop Techs in the shop office can assist you with storage lockers. Contact the Student Shop Manager (Eric Pulse) to reserve space for the cages and workbenches. Storage will be assigned based on availability and the specific needs of your project. Students must provide their OWN combo lock, no keyed locks.

24-hour Computer Labs

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

- 192-329

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.

- 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 screen-sharing, audio-, and video-conferences, use the Zoom Conferencing tools (see https://servicedesk.calpoly.edu/zoom-video-and-web-conferencing for info).

Conference Rooms

Room 192-133 is a small meeting room available for senior project teams to reserve. Visit the BMED Department (in 13-260) 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
- 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.

Conference Telephone Rules:

- 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/.

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/.

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.

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. For information about the shops, check out their website at https://machineshops.calpoly.edu/. Yellow Tag and Red Tag certification are both course requirements. Please refer to course syllabus for details.

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:

- 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.
- 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, and requires approval by your sponsor and your project advisor. See Contract Fabrication, below.
- 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 project advisor.

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

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.

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 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 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/.

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.

Applicable costs:

- $2/linear foot of Self-Adhesive Vinyl Sheeting (15” wide)
- $0.05/gram of PLA Printer Filament ($1 minimum per print)

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.

Rapid Prototyping (3-D Printing)

The BMED 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 industrially sponsored senior projects. Consult your project advisor for details.

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: A few websites that have been used by the BMED department and student clubs are listed below. This is by no means a comprehensive list, but it is a good starting point.
    - McMaster Carr:- Almost anything you could imagine. Freakishly fast delivery times. But, expensive. http://www.mcmaster.com/
    - Online Metals: Good for small orders of aluminum and steel structural shapes and tubes, http://www.onlinemetals.com/
    - Fiberglass Hawaii: Fiberglass, carbon, Kevlar, resins, molding materials, etc., http://www.fiberglasshawaii.com/

Testing Resources

Designs are verified by some combination of analysis, similarity to existing hardware, inspection, and testing. It is a requirement of the BMED senior project class that every project includes a planned DOE 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 BMED department at Cal Poly.

Testing Consultants

The BMED department may have access to 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 project 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.

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 BMED department has access to 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 for 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 or 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

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.

SUPPLEMENTAL READING

Design Process and Methodology

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

- Establish a need
- Explicitly state the problem
- Generate possible solutions
- Evaluate the solutions and pick the best one
- 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 two quarters

WORKING ON A TEAM

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 over two quarters. 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.

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. These stages are shown 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 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.

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?

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. These people are often reluctant to delegate authority and they worry about progress.

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:

- Will you agree this is what the team should do next?
- Can you go along with this position?
- Can you support this alternative?

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:

- Initially ask each question of the entire team.
- Pause and allow the team members time to consider the questions.
- If a team member responds, acknowledge the remark and explore the response further if possible or necessary.
- If no one responds, either ask a particular person or consider reworking the questions.
- Avoid biased questions
- Avoid asking too many yes/no questions
- 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. Below are guidelines by Scholtes that can be helpful when providing this type of feedback.

START WITH	EXPLANATION
"WHEN YOU…"	Describes the behavior
"I FEEL.."	Tells how you are affected
"BECAUSE I…"	Why you are affected that way
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:

- Stay Neutral: Everyone has a right to their own feelings. The team should acknowledge the expression of those feelings
- 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.
- Avoid asking team members why they feel a certain way.
- 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.

- Avoidance: This is the "bury your head in the sand" approach; hoping that the problem will go away. It never does.
- Accommodation: Some team members give up their position just to be agreeable, but this costs the team their input.
- 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"
- 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.
- 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.

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SOCIAL STYLES

Background and Motivation

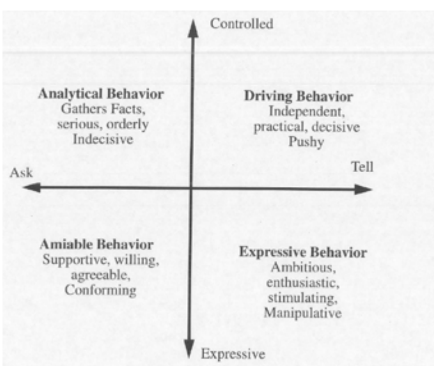
One of the most important skills that a team can develop is the ability to manage the diversity inherent among its members. This diversity is one of the strengths of using teams to solve complex problems like your design project. Managed properly, the team’s diversity can be leveraged to provide high 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.

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 opposites. 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 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.

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.

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QFD: Quality Function Deployment

Background

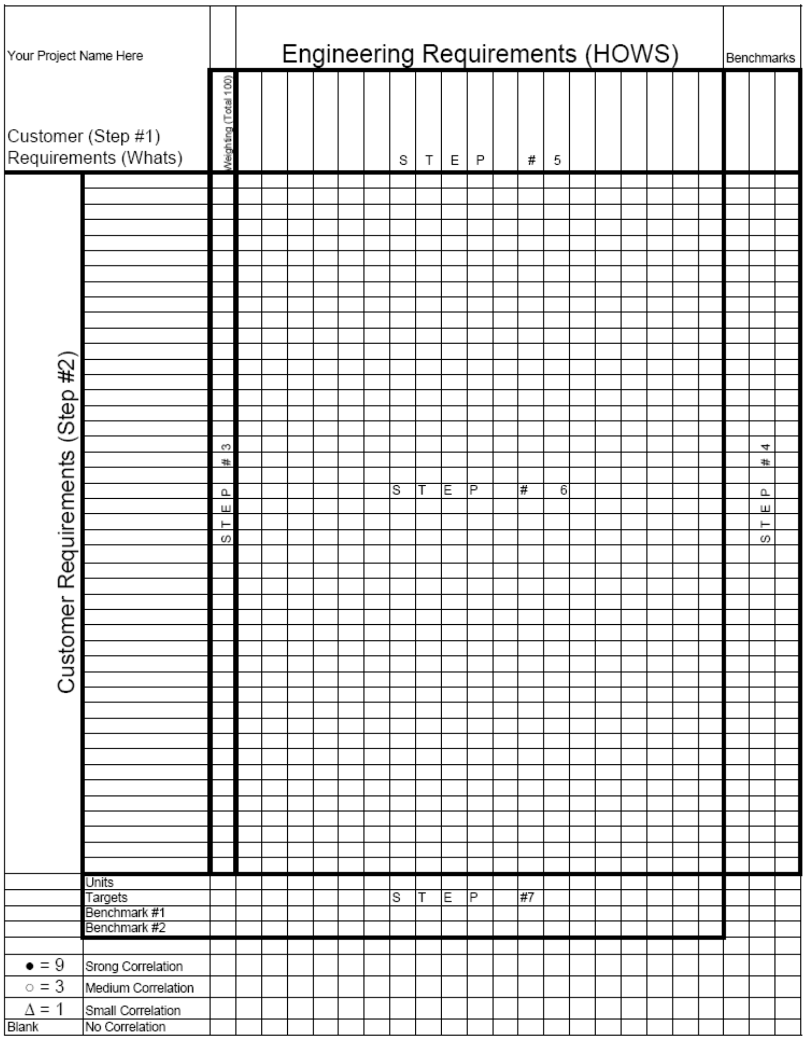
One of the first and most critical tasks in developing a product is understanding the problem. Individuals and companies large and small have been known to spend incredible amounts of time and money, solving the wrong problem and developing products or devices that do not satisfy the original need. This 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 difficultly 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.

Steps for the Method

Below is 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)



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 Requirements (Whats)

Different customers want different things in a design. A customer requirement 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 requirements, 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 requirements of your own as you will in some respects act as the manufacturing customer of your project. Once you have made a list of customer requirements you will probably want to sort them into like categories. Categories that usually come up include:

- Functional Performance
- Human Interaction
- Physical Requirements
- Reliability
- Life Cycle Concerns
- Resource Concerns
- Manufacturing Concerns

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. Whats)

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 Requirements (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 Requirements list and determine how you can measure some aspect of each requirement. It is very common to have multiple specifications for each customer requirement.

Step 6 – Relating Customer Requirements to Engineering Specifications (Hows vs. Whats)
This step involves determining the relationship between each customer requirement 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
Δ = 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.

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 you 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.

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DESIGN THINKING AND CREATIVE TECHNIQUES

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 imaginative solutions, which are both valuable and innovative."

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.

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.

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. cell phones, roommates, 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.

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 outline 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!

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, miniaturized, lowered, shorter or lighter?
- What can be substituted? Who else instead? What else instead? Other ingredients, other materials, other parts, other power, other places, other approaches, other processes?
- What can be rearranged? Can components be interchanged? Other patterns, other layouts, other orders, switch cause and effect, difference speeds, different schedules?
- 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 an 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 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:

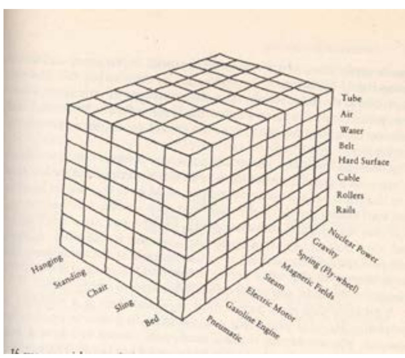
- Round, steel shank
- Wooden handle attached by a rivet
- Wedge-shaped end for engaging a slot in a screw
- Manually operated

- 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 to evaluate 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.



Last Thoughts on Creativity:

When working at being creative there are two major points to keep in mind:

- Everyone can be creative
- 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!

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