Engineering Capstone: A Guide to Senior Design for Engineering and Technology

ENGINEERING CAPSTONE: A GUIDE TO SENIOR DESIGN FOR ENGINEERING AND TECHNOLOGY

ELISSA LEDOUX; MOHAMMAD UDDIN; NICHOLAS MATTA; AND MATTHEW SHEPPARD

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INTRODUCTION

Elissa Ledoux

Engineering Senior Capstone courses are the hallmark of a B.S. in engineering degree, where students prove they are ready to become engineers. In these courses, students use prior knowledge and independent research to design, build, test, and analyze a system in their engineering discipline as a team. As such, it is a required course by virtually all engineering programs worldwide.

In all these courses, students apply the technical knowledge and soft skills they have gained throughout their program, as well as new principles and techniques they learn throughout the course, to solve a complex engineering problem requiring the invention of a new machine, system, or process. Due to the broad variety of projects, problems, and topics the capstone courses address, there is a deficit of textbooks and course materials wholly applicable. There is no one-size-fits-all solution.

Faculty at Middle Tennessee State University and East Tennessee State University have partnered to solve this problem, developing a textbook to streamline the capstone course instruction by developing, consolidating, and organizing open educational resources (OER) materials into one place. The final product is a module-based OER platform that includes handouts/slides, videos, and downloadable worksheets and grading rubrics for student assignments. There are seven (7) modules, based on the ABET Accreditation Criteria for 4-year Bachelor of Science programs in Engineering and Engineering Technology. Each module focuses on a specific Student Outcome (SO) listed in the Criteria and provide open educational resources for both knowledge and application aspects of student learning, centered around the SO. These categories consist of:

1. Problem Solving – Applying Prior Knowledge and Skills
2. Design – Ideation and Invention
3. Communication – Written, Oral, and Graphical
4. Ethics – Responsibilities, Safety, Global Impacts, and Standards
5. Teamwork – Collaboration and Project Management
6. Experimentation – Testing and Analysis
7. Learning Strategies – Research and Troubleshooting

Each module consists of both informational materials (lecture slides, handouts, videos, etc.) addressing the knowledge component, and student activities (assignments, worksheets, etc.) for the application component.

While technical skills help an engineer keep a job, the soft skills help them get the job. So in addition to the SO, there will be a bonus module focusing on career readiness, an area in which many students feel underconfident or unprepared in presenting themselves as they transition from college to the real world.

8. Career Readiness – Personal Presentation and Job Applications

This will develop students' soft skills, such as interviewing, resume and cover letter writing, and developing a professional employment profile. Informative and applicable materials will help equip students with the tools they need to be well-rounded and successful individuals, with the personal presentation skills required to rise through the ranks professionally.

The creation of this open educational resource (OER) was made possible by a Cycle 4 Grant from the Tennessee Board of Regents, as well as guidance from MTSU and ETSU. We are grateful for the commitment of MTSU, ETSU, and Tennessee for funding OER projects and ultimately making education more accessible to all. The front cover image was generated by AI and edited by the authors.

APPLICABLE COURSES

This guide is applicable to **any senior design capstone course for Engineering or Engineering Technology** and can also be used to guide design projects for underclassmen. Specific relevant courses at the authors' institutions are:

Middle Tennessee State University

- ENGR 4580 Mechatronic System Design
- ENGR 4590 Automation System Design
- ET 4801 Computer Engineering Technology
- ET 4802 Electromechanical Engineering Technology
- ET 4803 Mechanical Engineering Technology

East Tennessee State University

- ENGR 4950 Senior Design I
- ENGR 4960 Senior Design II
- ENTC 4600 Technology Practicum
- METC 4001 Senior Design Project 1
- METC 4002 Senior Design Project 2

1.

MODULE I: PROBLEM SOLVING

Problem Solving: Applying Prior Knowledge and Skills

Elissa Ledoux; Nicholas Matta; and Matthew Sheppard

ABET Student Outcomes

ENGR Student Outcome 1: an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics

ET Student Outcome 1: an ability to apply knowledge, techniques, skills and modern tools of mathematics, science, engineering, and technology to solve broadly-defined engineering problems appropriate to the discipline

Problem Solving is the most important skill for an engineer. This module includes theory and design practices focusing on the basics of mechanical and electrical systems. Much of the material is review and highlights from discipline-specific courses that students can reference. Students should review all material relevant to their portion of the project, to start the project off on the right track and avoid delays caused by designing or building something in a less-than-ideal manner.

I.0) Capstone Project Course Overview

As a student in an engineering capstone course, you will work in teams to design, prototype, and program machines. This is the most important course of your academic journey, where you prove that you are ready to be an engineer by applying prior knowledge plus independent research to solve open-ended problems as part of a team. In addition to producing a functioning prototype, deliverables include a complete technical documentation package and oral presentation to a panel of judges. Success will require coordinating with your teammates, your sponsor, your instructor, and participating in person. This is a very time-intensive course, and you should plan to spend an additional 10-15 hours each week outside of class so your team will have a functioning prototype and quality documentation by the end.

Sample downloadable introductory slides for instructors are provided below in editable formats:

ETSU Capstone Introduction & Syllabus

Overview of ENGR 4950 4960

I.1) Construction Refresher

A construction engineer plays a pivotal role in the planning, designing, and executing construction projects, ensuring that structures are built safely, efficiently, and within specified budgets. They collaborate with architects, project managers, and other professionals to translate design plans into tangible constructions, overseeing the entire building process. Construction engineers are responsible for selecting materials, coordinating schedules, and implementing construction methodologies. Their expertise covers a wide range of engineering disciplines, encompassing structural, geotechnical, and environmental considerations. Additionally, construction engineers must adhere to building codes, safety regulations, and sustainability practices, contributing to infrastructure projects' successful and sustainable development.

Information

- **Construction estimating** involves predicting the total cost of a construction project by accounting for all potential expenses, including both direct costs like labor and materials, and indirect costs such as permits and overhead. Accurate estimates are essential to ensure projects remain within budget and are completed profitably. This process includes reviewing bid documents, conducting site visits, and meticulously accounting for every known cost.
- Access the information on Construction Estimating by clicking the hyperlink below
    - Construction Estimating Overview– PowerPoint

- **Surveying** involves making precise measurements of the Earth's surface to determine the relative positions and distances between points. It is crucial for construction, land development, and mapping, providing accurate spatial data for engineering and infrastructure planning. This practice uses specialized instruments and techniques to gather, process, and interpret measurement data.

- Access the information on Surveying by clicking the hyperlink below
    - Introduction to Surveying – PowerPoint
- The pdfs below contains in-depth information on calculating measurements.

    - Topographic maps use contour lines to represent the Earth's surface, showing elevation and terrain shape. Contour lines connect points of equal elevation, with close lines indicating steep slopes and spread-out lines indicating gentle slopes. These maps are crucial for construction, land development, and outdoor activities.
        - TOPO MAPS AND CONTOURS – PDF
    - Differential leveling measures the vertical distance between points to determine their relative elevations. Using a level instrument and a leveling rod, surveyors take readings from a known elevation point to the point of interest. The difference between these readings provides the elevation of the new point.
        - DIFFERENTIAL LEVELING – PDF
    - A compass rule traverse computation worksheet is an essential tool in surveying used to adjust the coordinates of a traverse to account for measurement errors. The compass rule, also known as the Bowditch rule, is based on the principle that

errors in a traverse are proportional to the lengths of the traverse legs. This method helps ensure the accuracy and reliability of the survey data.

- **Traverse Data**: This section includes the measured angles and distances between each pair of traverse points. These measurements are the raw data collected during the field survey.
- **Initial Coordinates**: The starting coordinates of the traverse points, often based on a known reference point or benchmark. These coordinates serve as the baseline for the computations.
- **Error Calculation**: This step involves determining the total error in the traverse by comparing the measured coordinates with the known or calculated coordinates. The total error is the discrepancy between the starting and ending points of the traverse.
- **Error Distribution**: The compass rule distributes the total error proportionally to the length of each traverse leg. This means that longer legs will receive a larger portion of the error correction. The formula used is:
    - Correction= (Total Error x Length

of Leg) / (Total Length of Traverse)

- **Adjusted Coordinates**: After distributing the errors, the worksheet provides the corrected coordinates for each traverse point. These adjusted coordinates are more accurate and account for the measurement errors identified.
    - COMPASS RULE TRAVERSE COMPUTATION WORKSHEET – PDF

I.2) Manufacturing Refresher

A manufacturing engineer focuses on creating, refining, and optimizing manufacturing processes and systems to achieve efficient and cost-effective production. Collaborating with other engineering fields like mechanical, electrical, and industrial engineering, they work to enhance production methods, boost product quality, and lower costs. Their duties encompass analyzing workflows, integrating automation, choosing suitable equipment, and ensuring that manufacturing processes comply with safety and quality standards. By emphasizing process improvement and innovation, manufacturing engineers are essential in boosting productivity and maintaining a competitive edge across various industries.

Access the PowerPoint Refresher material covering the rules for using machine workspaces below:

These rules are general guidelines to provide a safe working environment.

- ETSU Room 103 Lab Rules – PowerPoint

I.3) Electronics Refresher

An electronics engineer focuses on designing, developing, testing, and maintaining electronic systems, circuits, and components. They leverage principles from electrical engineering to create technologies that manipulate electrical signals for various applications. Working in diverse fields such as telecommunications, consumer electronics, and control systems, electronics engineers drive technological advancements by designing and optimizing devices like microprocessors, sensors, and integrated circuits. Their responsibilities include system design, circuit design, prototyping, testing, and ensuring quality and reliability. By emphasizing innovation and efficiency, electronics engineers play a crucial role in shaping modern technology and enhancing everyday life.

Information

- **AC (Alternating Current)** circuits feature currents that periodically reverse direction, usually following a sinusoidal pattern. They are widely utilized in residential and industrial power systems because they efficiently transmit energy over long distances.

Clicking on the following PowerPoint refresher links below provides in-depth material covering AC circuits:

- Alternating Current (AC) from allaboutcircuits.com
  - 1. Basic AC Theory
  - 2. Complex Numbers
  - 3. Reactance and Impedance—Inductive
  - 4. Reactance and Impedance—Capacitive
  - 5. Reactance and Impedance—R, L, And C
  - 6. Resonance
  - 7. Mixed-Frequency AC Signals
  - 8. Filters
  - 9. Transformers
  - 10. Polyphase AC Circuits
  - 11. Power Factor
  - 12. AC Metering Circuits
  - 13. AC Motors
  - 14. Transmission Lines

- **DC (Direct Current)** circuits feature currents that move in one steady direction. They are frequently employed in battery-operated devices and electronics because they provide a reliable and constant voltage.

Clicking on the following PowerPoint refresher links below provides in-depth material covering DC circuits:

- **Direct Current (DC)** from allaboutcircuits.com
    - 1. Basic Concepts Of Electricity
    - 2. Ohm's Law
    - 3. Electrical Safety
    - 4. Scientific Notation And Metric Prefixes
    - 5. Series And Parallel Circuits
    - 6. Divider Circuits And Kirchhoff's Laws
    - 7. Series-parallel Combination Circuits
    - 8. DC Metering Circuits
    - 9. Electrical Instrumentation Signals
    - 10. DC Network Analysis
    - 11. Batteries And Power Systems
    - 12. Physics Of Conductors And Insulators
    - 13. Capacitors
    - 14. Magnetism and Electromagnetism
    - 15. Inductors
    - 16. RC and L/R Time Constants

- **Digital circuits** handle and transform digital signals, which correspond to binary values (0 and 1). These circuits are essential to modern electronics, facilitating tasks such as arithmetic calculations, logic operations, and data storage.

Clicking on the following PowerPoint refresher links below provides in-depth material covering Digital circuits:

- Digital Circuits from allaboutcircuits.com
    - 1. Numeration Systems
    - 2. Binary Arithmetic
    - 3. Logic Gates
    - 4. Switches
    - 5. Electromechanical Relays
    - 6. Ladder Logic
    - 7. Boolean Algebra
    - 8. Karnaugh Mapping
    - 9. Combinational Logic Functions
    - 10. Multivibrators
    - 11. Sequential Circuits
    - 12. Shift Registers
    - 13. Digital-Analog Conversion
    - 14. Digital Communication
    - 15. Digital Storage (Memory)
    - 16. Principles Of Digital Computing

- **Semiconductors** possess electrical conductivity that falls between that of conductors and insulators, making them crucial for modern electronics. They are integral to devices like computers and smartphones, where they regulate electrical flow and enable functions such as amplification, switching, and energy conversion.

Clicking on the following PowerPoint refresher links below provides in-depth material covering Semiconductors:

- Semiconductors from allaboutcircuits.com
  - 1. Amplifiers and Active Devices
  - 2. Solid-state Device Theory
  - 3. Diodes and Rectifiers
  - 4. Bipolar Junction Transistors
  - 5. Junction Field-effect Transistors
  - 6. Insulated-gate Field-effect Transistors
  - 7. Thyristors
  - 8. Operational Amplifiers
  - 9. Practical Analog Semiconductor Circuits
  - 10. Active Filters
  - 11. DC Motor Drives
  - 12. Inverters And AC Motor Drives
  - 13. Electron Tubes

I.4) System Salvation

Best practices for electronics and control for a reliable system that doesn't burn up.

Video: Sensor Redundancy

Video: Feedback Controls

Video: Microcontroller Protection

I.5) Actuator Specification

Information

An actuator is the prime mover for a mechanical system. The most common actuators are motors (electromechanical), and cylinders (pneumatic or hydraulic), although other types of actuators such as solenoids and pumps are also possible. How many actuators and what types are needed for a system depends on the application, available power sources, size and weight constraints, budget, and types of motion required. Motion can be linear or angular, continuous or discrete, and transmissions can be used to convert from one to the other. It is easiest to use as few actuators as necessary to reduce complexity, cost, and weight, although one actuator per degree of freedom is required. For similar reasons, it is also advisable to stick to one energy domain (either mechanical or fluid power). In senior design projects, pneumatics are preferred over hydraulics due to their lighter-duty applications and lower mess.

Actuators are selected based on effort and flow.

- motor: effort = torque, flow = angular velocity
- cylinder: effort = force, flow = linear velocity or displacement

These specs will be listed on manufacturers' websites in the product information pages. To determine the required effort and displacement for the actuator, calculations are required. These calculations should take into account the mass or inertia of the system, the resistance caused by friction and damping, and the effects of system position. The following materials explain how to calculate required motor torque and speed for an application.

One or more interactive elements has been excluded from this version of the text. You can view them online here: https://mtsu.pressbooks.pub/engineeringcapstone/?p=5#oembed-1

Motor Specification Handout: written version

Activity

For your project, determine how many actuators you need for your system, and what kinds they should be (motors, cylinders, solenoids, pumps, etc.). Using the worksheet below, calculate the required effort and flow for each actuator. You will need to use the information from the above video and handout, as well as your knowledge of dynamics, and for more advanced systems, you may need to search online for additional information.

Actuator Specification Worksheet

I.6) Sensors

Information

Sensors are used to provide feedback on a system's internal or environmental conditions. They increase consistency and quality of data, and save time for humans by helping to close the loop in system operation. The following videos provide an introduction to sensors, types, pros and cons, and redundancy.

One or more interactive elements has been excluded from this version of the text. You can view them online here: https://mtsu.pressbooks.pub/engineeringcapstone/?p=5#oembed-2

Sensor Intro explains sensor purposes and categories.

Sensor Types describes various types of sensors and their applications.

Sensor Pro and Con discusses the pros and cons of using sensors.

Sensor Redundancy details the practice and benefits of using multiple sensors to measure the same signal.

Activity

Use the worksheet below to help identify what types of sensors and how many of each your project needs. Choose the sensors based on what functions your system does, how it interacts with its environment, and what data must be shown to the user.

Sensor Identification Worksheet

I.7) Controls

Controlling your system can be done in different ways. Open loop control uses no sensors, while closed control loop does. Bang-bang control is simplest, and PID control is smoothest, but there are other options, too. This video playlist explains different types of control and how the choice of sensors and mathematical parameters affect your system.

Videos: in Controls Playlist

One or more interactive elements has been excluded from this version of the text. You can view them online here: https://mtsu.pressbooks.pub/engineeringcapstone/?p=5#oembed-3

- Introduction to Controls: open and closed loop control and block diagrams
- System Modeling: dynamic modeling of a plant
- System Order: 1st and 2nd order systems
- Controller Design: PID/RLC controllers, with specific focus on PD design
- Root Locus: root locus plots and comparison for 2nd order systems

- Feedback Control: methods and types, including bang-bang and PID

2.

MODULE II: DESIGN

Design: Ideation and Invention

Elissa Ledoux and Nicholas Matta

ABET Student Outcomes

ENGR Student Outcome 2: an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors

ET Student Outcome 2: an ability to design systems, components, or processes meeting specified needs for broadly-defined engineering problems appropriate to the discipline

Engineering design is a process of devising a system, component, or process to meet desired needs and specifications within constraints. (ABET, 2024) This module covers the engineering design process, from brainstorming to project planning and economics, including the business aspect to contextualize the project in the real world.

II.1) Design Process

The engineering design process is an iterative cycle of design-build-test-repeat. It starts with identifying the problem, then brainstorming solutions and choosing the best one to implement. From that concept, develop a more detailed solution with mathematical calculations and 3D CAD, then build the device, test it, and evaluate the results. Make adjustments as necessary to improve quality and reliability, repeating the design-build-test cycle until the project is ready to deliver. This video provides an overview of the engineering design process using the real life example of robotic end effector design.

One or more interactive elements has been excluded from this version of the text. You can view them online here: https://mtsu.pressbooks.pub/engineeringcapstone/?p=23#oembed-2

II.2) Brainstorming

Information

Brainstorming is the first step in the engineering design process. The slide deck below explains the purpose and practice of brainstorming and design decision making in more detail.
Brainstorming Slide Deck
For instructors, an editable slide deck is available here:
Brainstorming Slide Deck – Instructors
The PowerPoint covering Brainstorming Techniques, Benefits, and Best Practices can be accessed below:

- Brainstorming – PowerPoint

Activity

After brainstorming, compare the best ideas with a design decision matrix. The worksheet below can be downloaded and filled in for each project.
Brainstorming Decision Matrix Worksheet

II.3) System Flow Diagrams

Information

System flow diagrams (SFDs), sometimes called process flow diagrams (PFDs) show the logical flow of a system process. This includes:

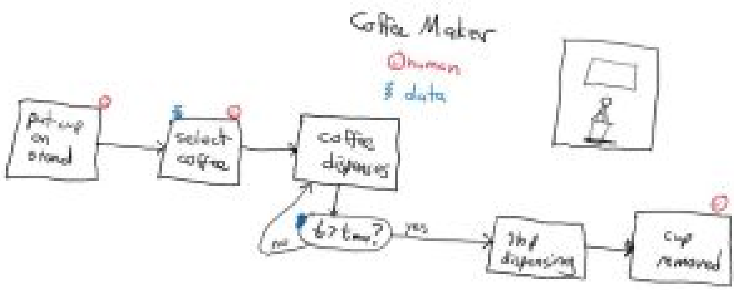
- Movement of product through system
- Conditional decisions
- Communication/messages
- Human-machine interaction

The process for constructing a system flow diagram is:

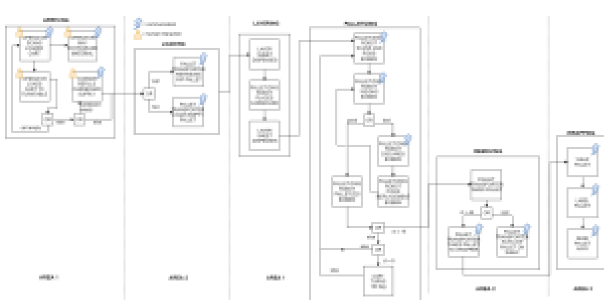
1. List functions of subsystems/components
2. Connect in order with logic
3. Indicate communication points
4. Indicate human interaction points

Often, actions are shown in boxes, states are shown in bubbles, and conditional decisions are shown in diamonds. However, that is not a hard and fast standard, and many companies develop their own technique. There is no standard for the symbol that identifies points of data/communication, or human interaction, as long as the style used is consistent and indicated in the map key.

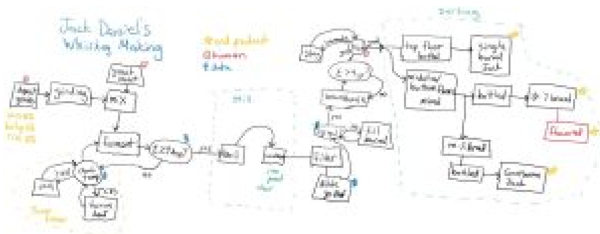
Examples of a simple system flow diagram, and two more complicated ones, are shown below:



Example 1: Coffee Maker



Example 2: Automated Packaging System



Example 3: Jack Daniel's Whiskey Making Process

Activity

Now make a system flow diagram for your project following the procedure above:

1. List functions of subsystems/components
2. Connect in order with logic
3. Indicate communication points
4. Indicate human interaction points

II.4) Budget and Bill of Materials

Information

Budgets and bills of materials (BOM) are two ways of quantifying the cost and materials for a project, and most projects use both. Budgets are more general, while bills of materials are more specific.

Budget: a budget is a breakdown of the total cost of a project, including both parts (materials) and labor (time). At the beginning of a project, it includes categories with cost estimates for each. There could be one category for structural materials, one for sensors and electronics, one for labor, etc. As the project progresses, line items are entered in the budget for money actually spent. At the end of the project, estimated cost and actual cost are compared by category to guide future project estimates. An example project budget is shown below.

Item	Qty.	Cost	Supplier	Part No.	Who Paid	Prototype
Guitar	1	$24	Star	MG50-BL	Revanth	1, 2, 3, 4
Alligator Clamps	2	$2	Radio Shack	270-346	Revanth	1, 2, 3
Pulley	1	$2.02	McMaster	3434T37	Matt	3, 4
Nylon Stud	10	$2.84	McMaster	93665A434	Matt	3, 4
LDPE	4 ft	$5.04	McMaster	8588K151	Matt	3
HDPE	4ft	$4.56	McMaster	8671K56	Matt	3
Polyurethane 90	.5 ft	$7.01	McMaster	2178T25	Matt	3
¼" Ball Bearing	1	$2.00	Fastenal	R4-2RS	Matt	4
¼" Threaded rod	3 ft	$2.50	Fastenal	T Rod Z	Matt	4
Aluminum Square Tube 1.5"	14"	$9.50	Metal Supermarkets		Dan	5, 6
3D Printed Overlay	2	$60	C Ideas	Polyjet 40A	Dan	5, 6
M3x5 bolts	4	$3	Fastener South		Alex	6
Steel Square Tube 1"x1/16"	36"	$10.82	Home Depot		Alex	6
M3x16mm screws (set of 2)	3 bags	$4.18	Home Depot		Alex	6
M3x20 screws (set of 2)	3 bags	$4.18	Home Depot		Alex	6
Total		$144				

Budget Example

Bill of Materials (BOM): a bill of materials is the "shopping list" of parts required to construct a prototype. It is a table listing the part number, name, purpose, price, quantity, and supplier. Some BOMs include other information such as urls or PO numbers for item purchase. A BOM only includes the materials required for the current prototype design, and not materials that were previously purchased and then abandoned, leftovers, etc. Donated items that were used on the project, as well as custom 3D-printed or machined parts, must be included for a complete BOM.

BOM Example 1 Click to see PDF

Part	Manufacturer	Part #	Qty	Unit Cost	Total Cost	Supplier
Arduino Mega 2560	Arduino	MEGA 2560	1	$38.21	$38.21	Amazon
Curtis Model 1228 Motor Controller	Curtis	1228	1	$430.00	$430.00	Nissan
5A, 30V DC Relay	DY	JZC-11F	5	$1.95	$9.75	SparkFun
5V Voltage Regulator	Texas Instruments	LM7812C	4	$0.70	$2.80	DigiKey
Tape Reader	Roboteq	MGS 1600	1	$445.00	$445.00	Nissan
RF Transciever	Nordic	NRF24L01+	2	$2.99	$5.98	eBay
Custom Fabrication (Chassis, Button Panel, Covers: $200 materials + $400 labor)	custom	N/A	1	$600.00	$600.00	Nissan
1/4" MDF Electronics Mounting Board	custom	N/A	1	$2.00	$2.00	Vanderbilt
				Total	$1,533.74	

BOM Example 2

Activity

For the first activity, make a forecasted budget for your project. Consider different categories such as structural materials, electronics, actuators, sensors, etc. and estimate how much you will spend on these. You may need to do a little research on how much certain items cost. Download the worksheet below to help organize your budget.

Cost Estimate Worksheet

As the project progresses and your design becomes more detailed, you will need to develop a bill of materials to list all the parts needed for your project. Your school may have a template for you to fill out when submitting a purchase order, or you can use the one below.

BOM Template

II.5) Computer-Aided Design (CAD)

Information

Computer-Aided Design (CAD) is the use of software to create 3D models and 2D drawings of parts and assemblies for manufacturing. CAD is typically developed first in 3D as part models, and then those parts are combined into an assembly to show how the full system fits and moves together. Many CAD programs include capabilities for stress/strain or fluids simulation. The benefit of building a system in CAD is that parts and designs can easily be changed or refined, and you can make sure the whole system fits together and moves as expected, before spending the money on parts and time on building something that might not work as expected. It is an essential preliminary design step that can prevent costly mistakes.

Several different CAD programs exist and many are available to students at free or reduced cost. The most common ones are listed below, along with details on licensing, tutorials, and certifications.

- **SolidWorks** ($49/year for students but might be free through your school)
  - License
  - Tutorials
  - Certifications
  - SolidWorks CAD Design Associate Practice Exam
- **AutoCAD** (free for students)
  - License
  - Tutorials
  - Certifications
- **Onshape** (free for students)
  - License
  - Tutorials
  - Certifications

After creating 3D parts, the models can be inserted into 2D technical design drawings using planar views. Here, dimensions, hole callouts, and hidden lines can be noted, and the drawings used for manufacturing of custom parts (i.e. machining). This guide by Joel Schadegg explains tips and best practices for creating a good technical design drawing.

The video Engineering Design Drawings: How to Make Prints a Machinist Will Love, by tarkka, explains the different types of engineering drawings, shows step-by-step how to make, choose, and place views and dimension common features, and provides ASME standards and example detail and assembly drawings of real parts.

One or more interactive elements has been excluded from this version of the text. You can view them online here: https://mtsu.pressbooks.pub/engineeringcapstone/?p=23#oembed-1

Activity

Build a 3D CAD model of your system to check the fit of all parts and verify that the dimensions meet the design constraints of your project. Make files for custom parts, and download files of purchased components from the manufacturers' websites or other free sites like GrabCAD or 3D Content Central. Create 2D drawings of any custom parts so you have a detailed plan for fabrication.

II.6) Ecosystem Mapping

Information

A product's design, features, cost, and profitability are affected by many factors. Ecosystem mapping is a way to identify all the external entities (people and organizations) affecting a project and see how your product fits into society. It shows the flow of materials, money, influence, and sabotage. This video explains how to make an ecosystem map and uses an example of an orthotic hand device.

One or more interactive elements has been excluded from this version of the text. You can view them online here: https://mtsu.pressbooks.pub/engineeringcapstone/?p=23#oembed-3

Activity

Make a map of your project's ecosystem. Include all people and organizations affecting the project, and link them with arrows showing the flow of materials, money, influence, and sabotage. Color-code the arrows or use different line types to distinguish between the different factors.

II.7) Market Analysis

Information

How much money can you make from your product? Is it profitable to enter the market? This shows how to analyze TAM, SAM, and SOM market sizes to determine possible revenue.

One or more interactive elements has been excluded from this version of the text. You can view them online here: https://mtsu.pressbooks.pub/engineeringcapstone/?p=23#oembed-4

Activity

Now use the worksheet below to analyze the market for your own project. Determine the target candidates for your TAM, SAM, and SOM, and use the internet to search for statistics on their demographics as well as a reasonable price point for your project based on similar existing products. Remember to cite all your sources! Is your project predicted to be a profitable venture?

Market Analysis Worksheet

3.

MODULE III: COMMUNICATION

Communication: Written, Oral, and Graphical

Elissa Ledoux; Matthew Sheppard; and Nicholas Matta

ABET Student Outcomes

ENGR Student Outcome 3: an ability to communicate effectively with a range of audiences

ET Student Outcome 3: an ability to apply written, oral, and graphical communication in broadly-defined technical and non-technical environments; and an ability to identify and use appropriate technical literature

Communication is the second most important skill for an engineer, right behind problem solving. Communication is the means of conveying information from your brain to others in an easily understandable form. This module covers written, oral, and visual communication techniques for reports, presentations, and posters.

III.1) Technical Documentation Overview

The book Howdy or Hello? Technical and Professional Communication, 2nd Edition, by Matt McKinney; Kalani Pattison; Sarah LeMire; Kathy Anders; and Nicole Hagstrom-Schmidt, CC-NC-SA, provides tools, strategies, and examples for technical documentation, including individual communication and group collaboration. Topics include:

- Collaborative writing: handling conflicts and challenges, documents and tools, meeting minutes, work logs, status updates, Gantt charts, collaborative writing process

- Correspondence: Email, letters, memorandums, text messaging / chatting, netiquette
- Instruction Sets: Preliminary steps, common sections, style, illustrations
- Proposals: preliminaries, design and formatting, language considerations
- Informational Reports: progress reports and lab reports
- Recommendation Reports: formatting, front matter, introduction, methods, results, conclusions, recommendations, references, appendices, tips
- Avoiding Plagiarism: plagiarism, references, quoting, paraphrasing/summarizing, APA citations
- Oral Communication: rhetorical devices, nonverbal communication, visual aids, presentation organization, preparation
- Applications: job, school, awards, transfers, promotions: resumes, curriculum vitaes, personal statements

III.2) Project Proposals

Information

The proposal is an original document used to define a project. In writing a proposal, the design team has seven objectives:

- Describe the sponsoring organization

- Describe the sponsor's problem and sponsor's motivation to work on the problem
- Define the objectives of the Design project
- Define and schedule the activities and tasks required to meet these objectives
- Specify and assign the resources necessary to complete the defined tasks
- Identify and schedule the deliverables for the sponsor
- Justify the suitability of the Design project

Activity

Write a proposal for your project using one of the guidelines here:
ETSU Project Proposal Assignment
MTSU Project Proposal Template

Your proposal will be evaluated using this rubric: Project Proposal Evaluation Sheet

III.3) Project Reports

Information

The project report is the document that gives the full story of your project. It should describe and justify your design with concise explanations, clear and labeled images, detailed analysis, and prototyping. It should explain your testing and results, and outline suggested design improvements. This is a working document for your specific project and may include other applicable information not listed in the outline. The extent of details and content will vary depending on the stage of the project, but the general sections of any project report are:

- Abstract: one-paragraph summary of project
- Introduction: how your project has a place in the world
    - background
    - project goals & design criteria
    - prior art (similar existing technology and inspiration):
- Design: the journey of prototype development, from brainstorming to final product
    - overview of full system and details on each subsystem
    - concept sketches or diagrams, 3D CAD images, and finally photos of the existing product
    - calculations and simulations such as actuator selection, structural analysis, and power draw
    - prototyping methods and reasons for component and materials choices
    - pneumatic diagrams, wiring diagrams, and pseudocode (code outline)
- Testing: proving that your project meets the goals

    - what tests you performed and how
    - photos and observations for qualitative results
    - tables, graphs, and statistical analysis (average, standard deviation) for quantitative results
- Conclusion: final thoughts and future work
    - successes of project and highlights of prototype performance
    - failures of project and suggestions for future improvement
    - list of any remaining work to be done, depending on project phase
- Appendices: anything relevant that did not fit above; examples are:
    - 2D dimensioned drawings / blueprints
    - detailed budget
    - bills of materials
    - control code
    - bibliography

Formatting the report professionally is essential so that the work turned in is clear, detailed, and quality – not a rough draft. Although every team member should look over the report before submission, one person should assume the responsibility of editor in chief. This person proofreads the report for content and grammar before submission, to make sure that the information is correct, formatting is consistent, all figures and tables are numbered and labeled consistently, and spelling and grammar are perfect.

Many universities have a writing center, with workers who will help students develop professional documentation to meet their instructor's guidelines. This is a fantastic option for those who want to take their reporting skills to the next level. Typically, students can send in (1) their report draft and (2) the instructor's grading rubric, outline, or project assignment sheet, and a worker at the writing center will review it for clarity of content and grammar. These workers will not necessarily know if your information is correct, but they will know if the structure and flow of your writing is clear and professional, good English, and be able to provide suggestions for improvement. Check your school's website for more information.

Beware of common pitfalls associated with group report collaboration! Common mistakes that severely diminish the appearance and quality of reports include:

- different contributors typing in different fonts or font sizes
- table of contents not reflective of actual page numbers
- figures or tables mis-numbered or inconsistently numbered
- undefined acronyms or nicknames for subsystems or components
- photos, graphs, or other images missing captions

- unclear or absent labeling of important features within the photos
- sections missing or insufficient due to procrastination
- citations missing or improperly formatted
- inconsistent verb person, number and tense (e.g. switching between first and third person, or past and future tense)

See Ch. 13 of Howdy or Hello? Technical and Professional Communication, 2nd Edition in section III.1 for additional report details and suggestions for group report collaboration.

Activity

Using whichever checklist below corresponds to the stage of your project, write a detailed project report. This document is one that you should draft once and then add to as your project progresses. Whether you organize the report by subsystems or by sections is up to you.

First Semester Midterm Report Checklist

First Semester Final Report Checklist

Second Semester Final Report Checklist

III.4) Product Assembly Guides

Information

The assembly guide, or technical specification, should describe your product design and assembly instructions in enough detail that someone could reproduce it using the documentation. This is different than the project report, because the project report focuses heavily on the reasoning and process for the design, as well a

s the testing and results, while the assembly guide focuses strictly on prototype parts and assembly. Think of it like your project came in a kit with all the items in the bill of materials, and now a technician must put them together to physically construct your system. Have clear explanations and labeled images, with a complete bill of materials, wiring diagrams, and dimensioned drawings. This is also a good place to link datasheets of off-the-shelf components so that the technician can refer to them for dimensions, wiring, or other specifics if needed. It is easiest to take photos of the prototype as you build it so that the instructions corresponding to the phases of assembly are easy to follow.

Activity

Develop an assembly guide or technical specification for your project, using the checklist below.

Assembly Guide Checklist

III.5) Project Executive Summaries

Information

An executive summary is written at the end of a project for the sponsor (or funder, auditor, customer, etc.), and is basically an extended version of an abstract, typically 2-4 pages in length, that defines the key takeaways from the project. This is written on a less technical level than the project report, and assumes an audience that is educated but not necessarily engineers. In writing a Project Executive Summary, the Design Team has four objectives:

1. Summarize the activities and tasks undertaken in the design project
2. Draw meaningful conclusions from the results of these activities and tasks
3. Make appropriate recommendations to the sponsor based on these conclusions

4. Define areas of further study for the sponsor

Activity

At the end of your project semester, write an executive summary of the project following the guidelines above. Send it to your sponsor along with other deliverables such as technical drawings and the project report, and invite your sponsor to the design expo. (Ask your course instructor for specifics on presentation style, date, and time.)

III.6) User Manuals

Information

The user manual should provide setup and operating instructions for your team's machine. This differs from the assembly guide in both audience and content. While the assembly guide is meant for a technician who is constructing the product, the user manual is meant for the end user or operator of the pre-built product. It should include text and photos, with enough details that a customer could use the device satisfactorily, as well as safety guidelines, a maintenance schedule, and a troubleshooting guide. The user manual should be similar to other user manuals you may receive when you purchase a product.

Activity

Develop a user manual for your product, following the checklist below.

User Manual Checklist

III.7) PowerPoint Presentations

Information

PowerPoint presentations are the most common form of oral presentation, and they are used in both academia and industry for explaining a project to an audience. This includes:

- Presenting a new idea to your boss
- Presenting the idea to donors
- Presenting new technical method in a conference
- Presenting the project to the community
- Giving a performance update to a team
- Summarizing a completed project for an audience

Basic things to think about when preparing a presentation are:

- What content is required?
- Who is the audience?

- What is the purpose?
- Where is all the equipment I need to present, and what connections are there?
- When am I on the program agenda?
- How long should I talk?
- How large is the room?

More specifically on presentation formatting, be sure to prepare visual aids, choose an appropriate color scheme and fonts, display information graphically when possible and keep text to short and to-the-point bullets. Tips and tricks for making and giving oral presentations are in the following slides.

Engineering Communication – Oral

A PowerPoint transition is a visual effect that appears when you switch from one slide to the next during a presentation. These transitions can make your presentation more dynamic and visually engaging. PowerPoint provides a wide range of transition effects, from subtle to dramatic. You can customize these transitions by adjusting their speed, adding sound, and selecting specific effects to match the tone of your presentation. By using transitions effectively, you can create a smoother flow between slides and enhance the overall impact of your presentation.

A Guide to PowerPoint Transitions

Activity

Prepare a PowerPoint presentation for your project, keeping in mind the points made above and adhering to the guidelines of your instructor and the rubrics below, whichever is applicable for your phase of work.

Midterm Presentation Rubric

Final Presentation Rubric

If you are a student at ETSU, a PowerPoint template can be downloaded here: ETSU Branded Powerpoint Slide Templates – 1600×900

If you are a student at MTSU, PowerPoint templates can be found here: https://creativeservices.mtsu.edu/templates/

III.8) Poster Presentations

Information

Poster presentations are common at conferences, science/design/research fairs, and technology expositions. At a poster presentation, the presenter engages in interactive, one-on-one discussions with an audience member. The presenter (you or your team) will use the poster and prototype as visual aids in a short (< 5 min) presentation, followed by an informal Q&A with the judge or other visitors. The poster should visually describe your project using relevant content, logical flow, and minimal text. The poster may follow slightly different formats depending on the event, so be sure to check if your event has specific guidelines on size, content, and format. General guidelines are below.

Design Project Poster Guidelines Printable Handout

Size:

A typical poster is 48″ wide x 36″ high. If you are making your poster in PowerPoint, **you will need to change the slide dimensions** because the default setting is not for posters. See the video on How to Change Slide Dimensions Here.

Fonts should be readable from 6′ away. This means the smallest font size on your poster should be size 50 pt.

Content:

A design project poster is different than a science project poster. This video gives tips on creating and organized and attractive poster to showcase your invention.

One or more interactive elements has been excluded from this version of the text. You can view them online here:

https://mtsu.pressbooks.pub/engineeringcapstone/?p=25#oembed-1

Required Content:

- Header: state the project title and who did it
  - First line (largest font): team name (if applicable) and title of project
  - Second line: team member names
  - Third line: course number, faculty advisor, sponsor if applicable
- Objective: 1-2 sentences describing the goal of the project and problem it is trying to solve
- Design criteria: bullet list of any constraints, specifications, or requirements for the project
- Product features: solution overview highlighting features or key components of the prototype
  - Include a photo with clean background, or 3D CAD, or an exploded view
  - Use labels, arrows, and text as appropriate
  - Include additional images such as user interface, diagrams of circuits, processes, or control operation, or timeline of design progression
- Test results: graphs, tables, and text quantifying the

performance of your prototype
- Conclusion: 1 sentence about the outcome of your project

Optional Content (include if applicable):

- References: cite properly using APA or IEEE format (author, title, date)
- Acknowledgements: if you had a company sponsor, donor, or actively involved mentor
- QR code linking to project video, website, or social media

Visually, the poster should follow this typical layout:

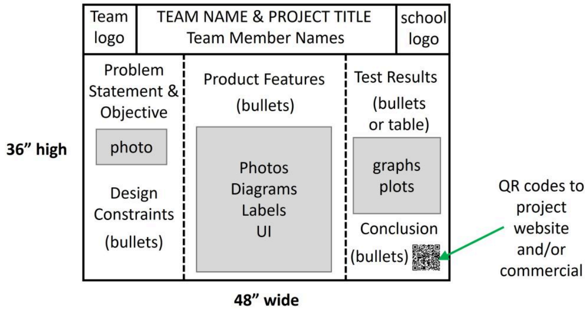


Fig. III.1: Example Poster Format

Activity

Develop a poster for your project using the guidelines and template provided. Customize the content as necessary to fit your project.

Engineering Project Poster Template

III.9) Project Pitching

Information

Being able to pitch your project in 1-2 min is essential for hooking a potential customer, employer, investor, or judge. The pitch can be used with either a poster, demonstration, or short PowerPoint presentation. A good project pitch hits four main topics:

1. Problem
2. Solution
3. Market
4. Assurance

The video below explains content and structure for a good project pitch.

One or more interactive elements has been excluded from this version of the text. You

can view them online here: https://mtsu.pressbooks.pub/engineeringcapstone/?p=25#oembed-2

The next video provides an example of a pitch for a robotic hand exoskeleton. This pitch won $2400 grant funding in a student competition.

One or more interactive elements has been excluded from this version of the text. You can view them online here: https://mtsu.pressbooks.pub/engineeringcapstone/?p=25#oembed-3

Activity

Develop an elevator pitch for your project using the guidelines below. Be able to sell your invention in 2 min or less, similarly to a commercial, so stick to the most important facts but speak persuasively.

[Project Pitch Guidelines]()

4.

MODULE IV: ETHICS

Ethics: Responsibilities, Safety, Global Impacts, and Standards

Elissa Ledoux; Matthew Sheppard; and Mohammad Uddin

ABET Student Outcome

ENGR Student Outcome 4: an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts.

All engineers have a responsibility to ensure their work and conduct meets a **standard of ethics**. While behaving ethically seems like common sense, it is not necessarily common sense or high priority to everyone, and so many professional engineering societies and associations have developed ethics guidelines to ensure that everyone shares and is aware of the same minimum standard. This module focuses on the awareness and practice of engineering ethics.

IV.1) Ethical Considerations

Information

Ethics is at the intersection of legality and morality and incorporates common sense as well as considerations related to responsibility. *Engineering* ethics are principles and guidelines engineers follow to ensure their decision-making is aligned with their obligations to the public, their clients, and the industry. According to the National Society of Professional

Engineers (NSPE), "Engineers, in the fulfillment of their professional duties, shall:

- "Hold paramount the safety, health, and welfare of the public.
- "Perform services only in areas of their competence.
- "Issue public statements only in an objective and truthful manner.
- "Act for each employer or client as faithful agents or trustees.
- "Avoid deceptive acts.
- "Conduct themselves honorably, responsibly, ethically, and lawfully so as to enhance the honor, reputation, and usefulness of the profession."

A printable handout of the code of ethics from NSPE is available here.

The following slide deck explains engineering ethics, key factors in decision making, and ethical guidelines in professional practice and technical writing.

Engineering Ethics Slides

Engineering ethics guidelines exist for topics such as:

- Public health, safety, and welfare
- Environment and sustainability
- Disclosure of concerns to clients
- Disclosure of concerns to authorities

- Employee competency
- Objectivity and honesty
- Duties to employers and clients
- Conflicts of interest and disclosures
- Confidentiality
- Personal merits and qualifications
- Credit to others
- Criticism of and interference with others
- Integrity of individuals and the profession
- Fraud, bribery, and legal violations
- Gratuities and compensation
- Personal professional development
- Professional development of colleagues
- Extending public knowledge of STEM
- Discrimination, harassment, and respect
- Partisan standards
- Serving as an expert witness
- Accuracy of advertising or descriptions of work
- Accepting criticism
- Reporting a member's ethics violations to a society

A complete chart of ethical standards by topic and discipline is available on the National Council of Examiners for Engineering and Surveying (NCEES) website at https://ncees.org/wp-content/uploads/U.S.-Codes-of-Ethics-handout-2019.pdf

The American Board of Engineering and Technology

(ABET) recognizes that not all the above topics apply to students who are not yet working as professionals. However, ABET does require in its accreditation criteria that **students must "recognize ethical and professional responsibilities in engineering situations and make informed judgments," and "consider the impact of engineering solutions in global, economic, environmental, and societal contexts"**. (ABET General Engineering Criterion 3. Student Outcome 4.) This applies to situational analysis, academic integrity, projects students do, and prototypes they create.

Activity

Many engineering design problems are narrowly focused with specific business-related objectives; however, there can be significant peripheral or concomitant impacts. Use the following worksheet to identify important ethics considerations related to your design, and describe the ways in which you accommodated that factor in your design, or justify your reasons for ignoring it. (Not all areas of ethics are applicable to a particular project, so be thorough and realistic in your analysis, but don't go overboard.)

ABET Design Factors Worksheet

IV.2) Engineering Standards

Information

Engineering standards are design, fabrication, and performance guidelines imposed by national or international organizations for the purpose of ensuring quality and safety of manufactured products and inventions. These include:

- ISO: International Standards Organization
  quality management (9000's), environmental management (14,000's), health and safety (45,000's), energy management (50,001), food safety (22,000's), and IT security standards (27,000's)
  https://www.iso.org/standards.html

- ASTM: American Society for Testing and Materials
  materials standards
  https://www.astm.org/Standard/standards-and-publications.html

- ANSI: American National Standards Institute
  equipment standards
  https://ansi.org/search

- NIOSH: National Institute for Occupational Safety and Health

health and safety research data and standards
https://www.cdc.gov/niosh/index.htm

- OSHA: Occupational Safety and Health Administration
regulations for general industry, construction, maritime, agriculture, recordkeeping, etc.
https://www.osha.gov/index.php/laws-regs

- NHSTA: National Highway Transportation Safety Administration
motor vehicle regulations
https://www.nhtsa.gov/laws-regulations

- IEC: International Electrotechnical Commission
guidelines and ratings for electrical and electronic devices and systems, IP
https://www.iec.ch/understanding-standards

Activity

Which engineering standards are applicable to your project? How will you consider and implement them in your design? Peruse standards from any of the organizations above that are related to your project. Choose at least 3-5 specific standards, list them, and explain how your project will meet them specifically. Add these to the last row of the table from the ABET Design Factors Worksheet in section IV.1 above.

IV.3) Shop and Lab Safety

Information

Workplace safety is one of the most important and highly regulated areas of engineering ethics. A safety mindset and safe practices begin in the home and develop in school lab activities. Each school and program has its own safety guidelines, but the handout below provides basic lab safety information that is widely applicable.

Lab Safety Guidelines

Activity

After reviewing the information in the lab safety guidelines above, take the Lab Safety Quiz.

If you have an industry-sponsored project, then after the initial site tour you have taken at your industry partner's facility, write an essay identifying potential ethical decisions you may have to navigate throughout your project this semester. Use the following assignment guidelines: Ethics Considerations on Your Capstone Project

IV.4) Case Study: Space Shuttle *Challenger* Disaster

Information

In 1986, the Space Shuttle Challenger disintegrated just seconds after launch, destroying all seven crew members on board and causing a three-month excavation effort in the Atlantic Ocean to collect all remains. The cause? O-ring failure. Watch the Space Shuttle Challenger Disaster: Ethics Case Study No. 1 video by the American Society of Civil Engineers and Allan J. McDonald, former director of the Space Shuttle Solid Rocket Motor Project, to learn about ethical issues uncovered in the investigation of this catastrophe.

One or more interactive elements has been excluded from this version of the text. You can view them online here: https://mtsu.pressbooks.pub/engineeringcapstone/?p=27#oembed-1

Activity

Primary Activity: *Challenger Investigation*. After viewing the video above, write an essay addressing the ethics questions in this assignment sheet: Challenger Ethics Essay Assignment Follow the guidelines for Applying Ethics in Technical Communication by Matt McKinney.

Secondary Activity: *Ethics Case Studies Debate.* The purpose of the presentation of these engineering ethics case studies is to explore these contemporary issues as a class. Five are available for debate here: Ethics Case Study Debate Topic Choices. Choose one of these to debate along with another team or classmate. Prepare your debate according to these guidelines: Ethics Case Study Debate Guidelines. You will be judged according to this rubric: Ethics Case Study Debate Rubric.

5.

MODULE V: TEAMWORK

Teamwork: Collaboration and Project Management

Elissa Ledoux; Mohammad Uddin; and Nicholas Matta

ABET Student Outcomes

ENGR Student Outcome 5: an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives

ET Student Outcome 5: an ability to function effectively as a member as well as a leader on technical teams

We all know the saying, "Two heads are better than one." While **teamwork** can spur a project forward much more efficiently and productively, and produce a higher quality end product, than one person working alone, that does not mean that collaboration is always easy! This module discusses tips and practices for efficient project management and smooth collaboration.

V.1) Project Scoping

Information

According to Katie Hanna et al. at TechTarget, project scope is "the part of project planning that involves determining and documenting a list of specific project goals, deliverables, tasks, costs and deadlines." The following video from Eye on Tech explains this in more detail:

One or more interactive elements has been excluded from this version of the text. You

can view them online here: https://mtsu.pressbooks.pub/engineeringcapstone/?p=30#oembed-1

Activity

Define your project scope, focusing on the goals and deliverables (tasks and deadlines will be addressed in the next section, V.2). Use the Project Scoping Template to format your document.

V.2) Gantt Charts and Timelines

Information

A Gantt chart is a graphical project timeline based on tasks and times to completion. It is in a bar chart form, where the horizontal axis represents time (dates) and the vertical axis indicates project tasks. This is a very common project planning tool that is easy to understand and facilitates project scheduling. The following slides explain the history of Gantt charts and steps for implementation.

Gantt Chart Schedule Slides

This video tutorial shows how to make an automated Gantt chart in Microsoft Excel.

Activity

Based on the information and tutorial above, make an automated Gantt chart for your project in Microsoft Excel. Use it as a guide to plan your semester and stay on track with project work to completion.

V.3) Critical Path

Information

The Critical Path Method (CPM) or Critical Path Analysis, is a graphical, logical and mathematically based algorithm for scheduling a set of project activities. It is basically a more detailed version of a Gantt chart based on a Work Breakdown Structure (WBS), which outlines the steps necessary for project completion and the time to complete each. CPM is commonly used with all forms of projects, including construction, software development, research projects, product development, engineering, and plant maintenance, among others. Any project with interdependent activities can apply this method of scheduling. The following slides explain the critical path method in three parts:

- Critical Path Method Part I – Basics
- Critical Path Method Part II – Calculations
- Critical Path Method Part III – Floats

Microsoft Project is a commonly used platform for critical path planning and analysis. The following video tutorials explain how to implement CPM in Microsoft Project.

- Part 1: Starting a Project
- Part 2: Creating a Schedule
- Part 3: Assigning Resources and Dependencies

Activity

Make a work breakdown structure for your project in Microsoft Project (or another project planning software available at your school). Calculate the float times and highlight the critical path.

V.4) Sprint Planning

Information

Sprint planning, sometimes called scrum, or scrum planning, is a way of identifying near-future goals, assigning tasks, and checking in on past assignments during a concentrated work period, typically 2-4 weeks. This is done in a 30-minute team meeting in order to keep the project on track and ensure that everyone is contributing to their full potential, operating in parallel rather than series to make progress more quickly as a team. The following video from Kaizenko explains this in more detail:

One or more interactive elements has been excluded from this version of the text. You can view them online here: https://mtsu.pressbooks.pub/engineeringcapstone/?p=30#oembed-2

Activity

At your weekly team meeting, review the accomplishments of the week, check in on each team member, and assign tasks moving forward. Fill out the template below as a team to organize your sprint. Seek help from your instructor or advisor, or additional resources where needed.

Sprint Planner Template

At the next meeting, everything in the "future goals" section should move to the "past accomplishments" section if the project is on track. If someone does not meet his or her goals for the sprint, check in with them. Are they overloaded, do they need help, or are they just slacking? Does anyone who finished early need more work to do or have an additional avenue in mind that they would like to pursue to take the project to the next level? Make adjustments to the sprint and timeline and set expectations as necessary.

V.5) Defining Success

Information

What is success?

Success means different things to different people, but it has two aspects:

- Theoretical: Did you give it your best shot?
- Practical: Did you reach the goal?

The Success Slides for Instructors offers a guided class discussion specific to team-based senior capstone projects.

Activity

Is your team on track for success? If not, how will you fix it? What are the next steps? Evaluate the state of your project mid-semester using the Success Worksheet. Then with your plan for the future and the given state of affairs, adjust your Gantt chart as necessary to reflect goals, timeline, and responsibilities for the rest of the term.

V.5) Professionalism

Student professionalism involves the behaviors, attitudes, and values that students display to show their dedication to their education and future careers. Key traits include responsibility, respect for others, honesty, integrity, and a commitment to excellence. By demonstrating professionalism, students show respect toward their professors and peers, reflect positively on their character, and prepare themselves for the responsibilities of adulthood. This foundation of professionalism is essential for success in both academic and professional settings, fostering a culture of respect, accountability, and continuous improvement.

The PowerPoint below contains information regarding key skills for academic and career success.

- Student Professionalism – Powerpoint

6.

MODULE VI: EXPERIMENTATION

Experimentation: Testing and Analysis

Elissa Ledoux; Mohammad Uddin; and Matthew Sheppard

ABET Student Outcomes

ENGR Student Outcome 6: an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions

ET Student Outcome 4: an ability to conduct standard tests, measurements, and experiments and to analyze and interpret the results to improve processes

Testing and analysis prove if a prototype or product meets the design constraints and lives up to its name. A finished build is not a finished product – one can't know a design is good unless its tested! This module covers best practices for prototype testing: data collection and analysis of results.

VI.1) Data Collection and Testing

Information

How does an engineer know if a system works as it should? How does an engineer know if a system meets the design requirements? He must test it! Quantitative testing is done through an organized procedure of data collection and statistical analysis. These statistics help the engineer to make decisions, solve problems, and design (or redesign) products and processes. The first part of the testing process is data collection, explained in the slide deck below.

Data Collection and Analysis Protocol in Engineering slide deck

Examples of test procedure / data collection forms are below:

- Example Test Procedure 1
- Example Test Procedure 2
- Example Test Procedure 3

Activity

Write a procedure for testing one aspect of your system or subsystems, following the examples above. (Each team member should write one for testing a different subsystem.) The document should include:

- Name of test and system/subsystem
- Required equipment
- Required personnel
- Objective
- Safety procedures
- Step-by-step test procedure in checklist form
- Photo of testing setup if applicable

The level of detail should be such that any competent classmate, engineer, or technician could perform the test and collect the data according to protocol without your help.

VI.2) Results and Analysis

Information

Once the testing data is collected, it needs to be analyzed in an organized fashion. Ideally, the results prove that the prototype meets the project design constraints both qualitatively and quantitatively. *Qualitative*pertains to the quality of results; i.e., how well does the prototype work (excellently, okay, poorly, etc.) *Quantitative*numerically characterizes performance in terms of accuracy, repeatability, and anything else relevant. It measures and reports actual numbers in table or graph form, analyzes those statistically (average, standard deviation, etc.), and compares them to the calculated/ predicted/goal values.

Different methods of statistical analysis are appropriate for different types and quantities of data. Common methods are:

- Two-sample hypothesis testing
- ANOVA
- Regression Analysis

This Statistical Analysis Methods slide deck explains the steps and examples to conduct each type of analysis.

After the data is collected and analyzed, it should be displayed in a manner that is easy for everyone involved to interpret. This includes engineers, managers, and customers.

Charts and graphs are the most preferable method of visualization, but plots and tables can also be used depending on the type of data. This slide deck on Creating Data Summary and Data Visualization provides recommendations and best practices for data display.

If the prototype does not meet or surpass the design requirements, a new iteration of the design cycle is required. If performance falls just barely short, only minor revisions are necessary, so tweak the prototype to improve performance. If the prototype breaks during testing, or proves inaccurate, unreliable, or woefully short of the design requirements, major revisions are necessary, so go back to the drawing board, redesign, rebuild, and retest.

Below are examples of results and analysis for prototypes that neared or exceeded all design requirements:

- Testing and Analysis Example – Robotic Lawn Mower
- Testing and Analysis Example – Rubik's Cube
- Testing and Analysis Example – Voice Ctrl Toolchest

Activity

After testing your prototype according to the testing procedures your team developed in the section VI.1 activity, analyze the results using appropriate methods as described above, and catalog them in the worksheet below. All design constraints can be evaluated qualitatively, and choose 3-5 aspects of your system's performance to evaluate quantitatively as well.

Testing and Analysis Worksheet

VI.3) Time Studies

Information

A time study is a cycle time analysis done for a task in order to identify minimum possible times and improve the efficiency of the process. Each process can be broken down into sub-tasks, videoed, and timed. This is done for several repetitions (sometimes with different people or machines depending on what activities are involved in the process), and the times calculated for each sub-task. Then areas for improvement can be identified and corrected in order to optimize overall cycle time.

The slide deck Time Studies Slides can be used by instructors to provide an overview of time studies and a guided class activity.

This Time and Motion Studies video by Beginning Engineers explains the basics of conducting a time study:

One or more interactive elements has been *excluded from this version of the text. You can view them online here: https://mtsu.pressbooks.pub/engineeringcapstone/?p=32#oembed-1*

Their next video, Time Study Examples, provides multiple examples of breaking down a process and conducting time studies:

One or more interactive elements has been excluded from this version of the text. You can view them online here: https://mtsu.pressbooks.pub/engineeringcapstone/?p=32#oembed-2

Activity

Following the procedures explained above, perform a time study for your project. First, break your system's process down into sub-tasks using the process flow diagram you developed in Ch. 2. Create a form for recording time data by trial and sub-task as shown in the examples above. Then test your system for multiple full cycles, while videoing. Re-watch the videos and note times for each sub-task, then identify areas to optimize. How can you make your system faster or more efficient? Can any superfluous motions be eliminated? Can any speeds be increased without sacrificing accuracy?

7. MODULE VII: LIFELONG LEARNING

Lifelong Learning: Research and Troubleshooting

Elissa Ledoux; Mohammad Uddin; and Matthew Sheppard

ABET Student Outcome

ENGR Student Outcome 7: an ability to acquire and apply new knowledge as needed, using appropriate learning strategies

Whether you are in school, on the job, or just moving through life, learning never stops (if it does, it's time to move on!). Engineers apply prior knowledge and independent research to solve problems: so if you don't know how to do something, tap into your resources, do some research, and figure it out! We can all learn from those who went before us, so we don't repeat the mistakes of history. This module covers practices for **lifelong learning**, as well as specific ways to apply these in senior design.

VII.1) Learning Strategies

In college, you approach the fountain of knowledge as an adult. Now, you are responsible for your own education. Your professors provide the opportunities to learn and the tools you need to succeed, but your success is now in your hands. As a senior in a capstone course, you will apply the knowledge you have gained over the last few years along with independent research to solve a new problem. This is the ultimate test. To succeed, you will need to be proactive, resourceful, organized, and efficient. The following slides offer tips on study skills and

learning strategies.
Slide deck: Study Skills and Resources

VII.2) Competitor Analysis

Information

Competitor Analysis consists of researching existing technology ("prior art") that is related to your project. This includes competing products on the market, research prototypes in development, or simply comparing different approaches to complete a system or subsystem's task. Inspiration can be found everywhere in the world, and old techniques in one area can be used to solve new problems in another. Competitor analysis is a great way to inform a design, because it reveals the positive and negative aspects of existing products, so that the new design can improve upon them. Information from several sources should be collected, so that the design is informed by a broad range of ideas rather than a narrow one. Sources include:

- Internet searches: this approach is best used for getting an overview of the competition landscape and finding what similar products, if any, exist on the market. It is important to note that not everything on the internet is true, so exercise caution in your search. Although websites with the extension .org tend to be the most trustworthy, in general, .com sites are more centered on commercial product information, and social media sites and television commercials tend to be the least transparent regarding technical product details. Product information in the form of videos, images, and text, can be found by searching in

  - Google
  - Bing (Microsoft Edge)
  - Duck Duck Go
  - Safari (Mac only)
  - Mozilla Firefox
  - YouTube
  - Instagram

- Scholarly searches: Patents and academic research publications provide more technical and honest design details than general internet searches do. These are more challenging to understand and digest, but can give excellent insight into the inner workings of a system or product. The most accessible scholarly search engines are:
  - Google Scholar (for research publications)
  - Google Patents (for patents)
    Your school's library website is also a good place to find publications and patents, and even when using Google scholar, being on your school's internet or logged in via VPN will provide access to many

more resources than not. This is because your school pays for subscriptions to research journals, while you personally would only be able to read "open access" publications otherwise.

- Personal contacts: discussing ideas and and asking questions to experts in the field can reveal insider knowledge that is hard to find reliably online. Your parents and their friends (if they work in your field of interest), sales or tech support phone lines, or other company representatives are all good resources to consult.

Activity

As a team, conduct a competitor analysis for your intended product. Each team member should research on his or her own to compile a list of existing products, research prototypes, or methodology, with descriptions, pro/con lists, and citations. Compare and compile everyone's findings using the worksheet below. How do these findings influence your project's design?

Competitor Analysis Worksheet

VII.3) Project Review Evaluation

Information

An evaluation of the performance of a project after it has been completed is useful for both personal and organizational improvement. Typically, a project review evaluation is an open-ended discussion of the strengths and weaknesses of the project plan and execution, and focuses on the following questions:

- Which aspects of project performance (e.g., development time, development cost, product quality, manufacturing cost) were most positive?
- Which aspects of project performance were most negative?
- Did any tools, methods, or practices contribute to the positive aspects of performance?
- Did any tools, methods, or practices detract from project success?
- What problems did the team encounter?
- What specific actions can the organization (i.e., the students and the instructor) take to improve project performance next year?
- Would you recommend that we work with your client in

future projects?
- What specific lessons were learned? How can they be shared with the students who take this course next semester?

Activity

Reflect upon your project over the past year or semester. Consider the highs and lows of your project performance, teamwork, sponsor interactions, and overall learning experience. Identify concrete areas of successes and failures among the above, and ways to improve. Write a project review evaluation using the guidelines below.

Project Review Evaluation Assignment

8.

MODULE VIII: CAREER READINESS

Career Readiness: Personal Presentation and Interview Skills

Elissa Ledoux and Mohammad Uddin

While technical skills help an engineer keep a job, the soft skills help them get the job. This is a bonus module focusing on **career readiness**, an area in which many students feel underconfident or unprepared in presenting themselves as they transition from college to the real world. This will develop students' soft skills, such as interviewing, resume and cover letter writing, and developing a professional employment profile. Informative and applicable materials will help equip students with the tools they need to be well-rounded and successful individuals, with the personal presentation skills required to rise through the ranks professionally.

Most universities have a career services center, where students can obtain one-on-one help with resumes and interviewing or attend group workshops. These centers also have websites with school-specific student resources for creating resumes and cover letters, and many offer a job applications portal as well. Many of the resources that follow in this chapter come from Middle Tennessee State University and East Tennessee State University. Check your school's website for information about career fairs, career prep, or other upcoming events and resources.

VIII.1) Resumes and CVs

Information

Resumes and curriculum vitaes (CVs) are organized handouts of your education and experience that you provide to employers when applying for jobs. These give an employer a quick look at who you are on paper and are the first part of the candidate selection process. Resumes and CVs are for separate purposes and have some notable differences:

- *Resumes:* meant for professional or industry job applications, this one-page info sheet highlights your education, skills, and experience. One page is the maximum length, unless you have an exceptional number of accomplishments or have been actively engaged in a field for 10+ years. Most employers will not read past the first page.
- *Curriculum vitaes:* meant for graduate school or academic job applications. Literally translated, “the course of life,” this is a lengthy list of your academic and professional history, including research publications, theses performed or advised, courses taught or developed, grants received, and conferences attended, in addition to the standard items from the resume. A CV could be 5+ pages depending on your accomplishments and length of time in the field.

Professional document resources (videos and downloadable templates) for resumes, CVs, and more can be found at this link. Additional resources include:

- Resume Writing Slide Deck (ETSU)
- Student Guide to the Professional Resume (MTSU)
- Best Practices: Resume Writing (ETSU)
- Student Guide to the Curriculum Vitae (MTSU)
- Resume Writing Video (MTSU)

One or more interactive elements has been excluded from this version of the text. You can view them online here: https://mtsu.pressbooks.pub/engineeringcapstone/?p=36#oembed-1

Activity

Are you headed for industry or graduate school? Make a new resume (or update your old one) using the tips, tricks, and templates above. Check it for length, spelling, grammar, and parallel structure. Be sure to eliminate anything from high school, except in rare occasions such as being valedictorian or a national champion in sports or other activities.

When you are finished, make an appointment at your university's career center, and ask a professional in your field (professor or family friend) to review it with you. Reviewing the document with multiple sources will be beneficial. The career center professional will be able to advise you on organization, wording, and correct English, while an engineer will be able to guide you on expressing discipline-specific skills and experience, and be able to tell you what items should be emphasized or eliminated.

VIII.2) Cover Letters and Personal Statements

Information

A cover letter or personal statement is the second part of an application.

- *Cover letters* are for industry or professional job applications and typically one page long. Resources for cover letter writing are below:
    - Cover Letter Writing Guide (MTSU)
    - Cover Letter Examples (ETSU)
    - Crafting Cover Letters Video (MTSU)

One or more interactive elements has been excluded from this version of the text. You

can view them online here: https://mtsu.pressbooks.pub/engineeringcapstone/?p=36#oembed-2

- *Personal statements* are for graduate school applications and typically two pages long. Resources for personal statement writing are below:
  - Personal Statement Writing Strategies (MTSU)
  - Creating a Personal Statement Video (MTSU)

One or more interactive elements has been excluded from this version of the text. You can view them online here: https://mtsu.pressbooks.pub/engineeringcapstone/?p=36#oembed-3

Activity

Are you headed for industry or graduate school? Write a cover letter for your dream job or a personal statement for your ideal school using the information. Check it for length, spelling, grammar, and relevant content. Be aware that because the cover letter is personal and relevant to the job or school desired, you will need to have a base letter that you can tailor as appropriate for the situation. Avoid the trap of using AI to draft this document, and speak from the heart! This is your story, and you can tell it more honestly and passionately than a robot.

When you are finished, make an appointment at your university's career center, and ask a professor to review it with you, too. Reviewing the document with multiple sources will be beneficial. The career center professional will be able to advise you on coherent and cohesive writing, while your professor will be able to guide you on relating personal experiences to your intended research trajectory, and help you to formulate goals if you don't know what you want.

VIII.3) Interviewing

Information

Interviewing is when the game gets real. One type of interviewing involves professional networking, such as speed interview events, career fairs, or conferences. That typically occurs before submitting a job application, and can lead to a personal in with the company. The second, more traditional type of interview occurs after an application has been accepted, and it is scheduled one-on-one with a company representative for an hour or more. After passing the first round of sit-down interviews, the company may initiate a weed-out process and invite the top few interviewees on site for an all-day more technical experience. The interview can make or break the job, so it is important to be prepared for all types.

Professional Networking

When you meet a potential employer at a career fair, networking event, or speed interviewing, you need to be prepared to pitch yourself in less than a minute. This is your opportunity to hook an employer on your qualifications and attitude, and present a favorable first impression. This forms the basis for your cover letter and should come from the heart. DO NOT USE AI TO WRITE AN INTERVIEW PITCH!!! It will sound fake and impersonal and not win the job. See the Interview Pitch Guidelines for more details.

Activity

Write an interview pitch using the Interview Pitch Guidelines. Revise and rehearse it so it flows smoothly, with proper English, and is 1-2 minutes long (approximately 1 page typed, double-spaced).

VIII.4) Linkedin Profiles

Information

Linkedin is a free professional networking site, where working professionals and job seekers can view each others' qualifications, find and apply for job opportunities, endorse each other for skills, post publicly, or message each other privately. A good Linkedin profile is important because it shows not just what you have done, but who you know, and employers will scout you for references and qualifications. A Linkedin profile is NOT a standard social media profile, but rather an online version of your resume or CV. So be sure to use a professional head shot (not a graduation photo or casual photo) and avoid posting about politics, religion, or your weekend (stick to professional or academic accomplishments, or congratulate others for theirs).

Additional resources for creating Linkedin profiles include:

- Tips for Using Linkedin (ETSU)
- LinkedIn Profile Checklist (Linkedin)

Activity

Make an account at https://students.linkedin.com/ and create your professional Linkedin profile based on the information above and the resume you already created in the section VIII.1 activity. If you do not have a professional head shot, put on a collared shirt, comb your hair, stand in front of a blank wall, and ask a friend to take one with your phone. When you are finished, add your instructors and 20 other people you know.

ABOUT THE AUTHORS

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Despite beginning as a preschool dropout, Elissa found her passion for academics and graduated from Louisiana State University in 2013 with a B.S. in Mechanical Engineering. She earned her M.S. and Ph.D. in Mechanical Engineering from Vanderbilt University in 2016 and 2024, focusing on lower and upper limb rehabilitation robotics research, respectively. After working in industrial robotics 2017-2018, she joined MTSU in 2018 as a full time lecturer for Mechatronics Engineering. Elissa teaches dynamics, kinematics, robotics, FE exam prep, and senior design capstone, and is passionate about making engineering education more effective and efficient for students, as well as connecting theory to application. She uses this textbook for the ENGR 4580 and 4590 senior design capstone courses for Mechatronics Engineering.

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