ENGR 1201

Introduction to Engineering Workbook

Tyler Junior College, Spring 2015

by Jim Sizemore, Tyler Junior College

Acknowledgements: In preparing this work I acknowledge work from many people including Gene Branum and Doug Parsons of TJC; Dr. Ronald W. Welch, PE, Dr. Fredericka Brown, and Dr. Hector Ochoa of UT Tyler; and Dave Galley of Collin College.

Main site: http://iteach.org/funphysicist/ with links to this workbook. Actual addresses:
Word: http://funphysicist.weebly.com/uploads/2/0/3/8/20383539/engr1201workbook02.docx and
PDF: http://funphysicist.weebly.com/uploads/2/0/3/8/20383539/engr1201workbook02.pdf

Margaret Hunt bridge near Dallas TX – photo by Jim Sizemore.

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Recommend Printing Instructions

- Yes to "Front & Back (recommended)" – that is, 2 sided copies
- Collate
- Do not staple
- Do not Hole Punch
- Spiral Binding
- No to Colored Paper – plain white
- No to Color printing
- Deliver to bookstore

Special Instructions
1. **PLEASE MAKE EVERY EFFORT TO DELIVER THIS TO THE BOOKSTORE BY THE FIRST DAY OF CLASS**
_____
2. **BINDING ON LEFT SIDE LIKE A REGULAR BOOK – NOT ON RIGHT**
3. Print in black & white
4. If possible print all copies from file-don't make Xerox & copy (due to photos/graphics not copying well).
5. **BLUE** cardstock front and back.
6. Print so odd numbered pages are on the right.
7. Deliver one copy to <your name>, <your office> (<your mailroom>)

TJC Bookstore Information
TJC Course Name: Introduction to Engineering
TJC Course Number: ENGR 1201
Instructor's Name: <your name>
Bookstore Up-Charge (if known): $5.00

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Profits from the sale of this workbook will go toward student activities and professional development.

Engineering Associate SUGGESTED Degree Plan
TJC 2014-2015

Due to different requirements at different four-year colleges and universities, **you MUST create a degree plan as early as possible with your intended four-year institution.** The following serves as a guideline for graduation and substitutions may be made with the permission of the department chair especially if there are conflicts with the four-year institution's degree plan.

SEMESTER I			**SEMESTER II**		
ENGL	1301	Composition I*	ENGL	1302	Composition II (or ENGL 2311)
MATH	2413	Calculus I	MATH	2414	Calculus II
CHEM	1411	General Chemistry I	PHYS	2425	University Physics I **(Spring)**
ENGR	1201	Introduction to Engineering	HIST	1301	United States History I (ME, CE, EE) ***OR***
ENGR	1304	Engineering Graphics	CHEM	1412	General Chemistry II (ChemE) ?
		Total Credit Hours = 16	EDUC	1300	Learning Framework
					Total Credit Hours = 17-18

SEMESTER III			**SEMESTER IV**		
ECON	2301	Principles of Macroeconomics ***OR***	ENGR	2305	Circuits I w/2105 lab (EE) ***OR***
ECON	2302	Principles of Microeconomics ?	ENGR	2302	Engineering Mechanics – Dynamics (ME) ***OR***
PHYS	2426	University Physics II **(Fall)**	COSC	1336	Programming Fundamentals I (EE) ***OR***
MATH	2415	Calculus III	CHEM	2425	Organic Chemistry II (ChemE) ?
ENGR	2301	Engineering Mechanics I – Statics (ME & CE) ***OR***	MATH	2320	Differential Equations
CHEM	2423	Organic Chem I (ChemE) ? ***OR***	SPCH	1321	Business and Professional Speaking (recommended) ***OR***
ENGR	2304	Programming for Engineers (EE)	SPCH	1315	Public Speaking
		Total Credit Hours = 14-15	HIST	1302	US History II ***OR***
			HIST	2301	Texas History
					Total Credit Hours = 13-14

Total Required Semester Hours = 60

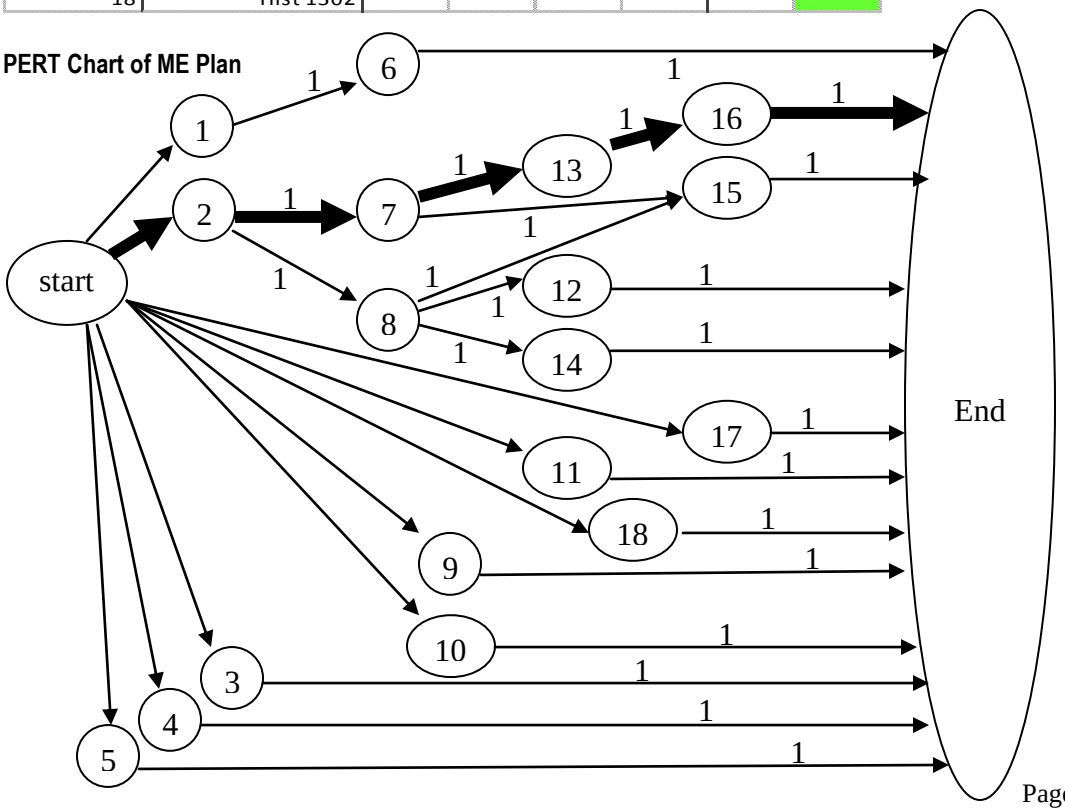
Notes:

- ME means Mechanical Engineering, CE means Civil Engineering, EE means Electrical Engineering, and ChemE means Chemical Engineering.
- ? means this course is not part of the engineering degree program according to the current catalog at this time.
- The curriculum for an AS in Engineering will not make the student core complete. It will be necessary to take core courses at the senior college or university
- Students should choose ENGL 1302 or ENGL 2311 based on senior college requirements.

Gantt Chart of ME Degree Plan

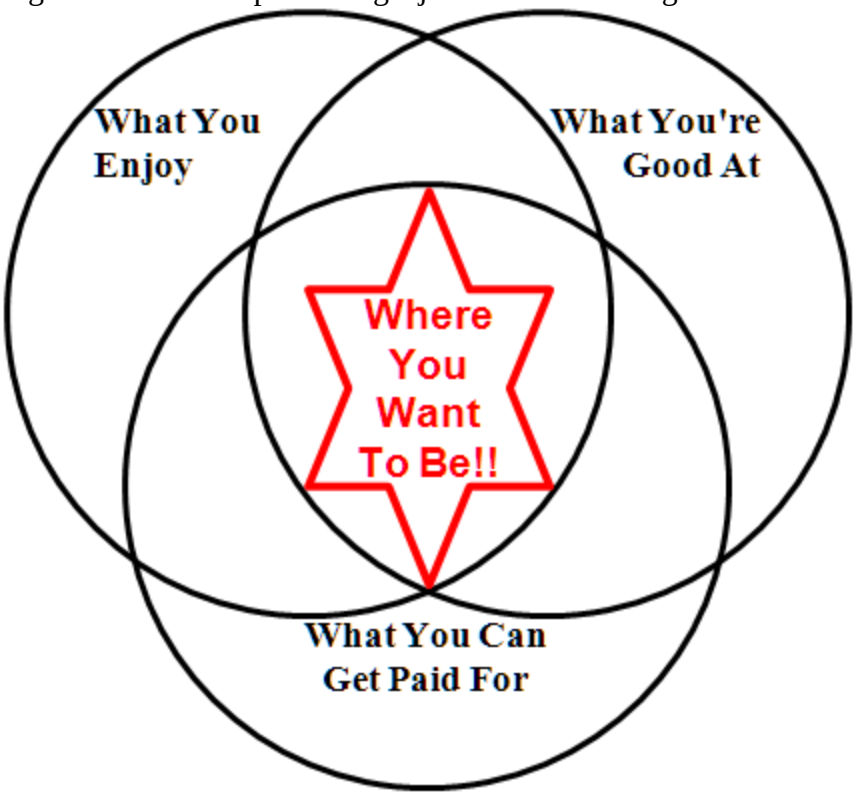
	Year ->	1				2	
		Semester					
Item	Course	Fall	Spr	Sum I	Sum II	Fall	Spr
1	Engl 1301						
2	Math 2413						
3	Chem 1411						
4	Engr 1201						
5	Engr 1304						
6	Engl 1302						
7	Math 2414						
8	Phys 2425						
9	Hist 1301						
10	Educ 1300						
11	Econ 2301						
12	Phys 2426						
13	Math 2415						
14	Engr 2301						
15	Engr 2305						
16	Math 2320						
17	Spch 1321						
18	Hist 1302						

PERT Chart of ME Plan



Planning for College

What are you going to do with the rest of your life? How is college going to help you get there? How are you going to finish college? What degree are you going to get? How will that degree help you get to the next step - finding a job or advanced degrees?



Most of you doing this assignment are just starting your career path and now is the time to think about these questions. **Figure out what you enjoy doing, what you're good at, and what you can be paid for then target where the three intersect.**

Steps To Get There **GRADUATE!** Get your two year diploma and be specific. It will take you longer to graduate if you get a general studies diploma from community college. **Aim for a specific goal and get THAT diploma.**

Assignment: Plan Your Courses to Achieve Your Degree Plan

Your mission is to map out, semester-by-semester, the courses you will need to get there. **Plan Your Work and Work Your Plan. Failure to Plan is Planning to Fail.**

- If you have partially completed your program, starting with this semester, show how you will finish it.
- If you have not decided yet, make your best guess now. It's easier to change your mind later than wandering aimlessly and deciding later.
- Because of work, etc., it may require more than four years. If so, show it.
- Add additional pages if needed (copy page after next).
- If you feel there is something unusual in your plans, explain those circumstances.
- Be specific.
- You have one week to complete this assignment - it is **due the first meeting of the second week of class.**
- Bug advisors and instructors for information.
- **Consult your intended four year college** – the information provided is generic and your four year college of choice may have some deviations. Do your homework now – it will save you time, energy, and money.
- Keep your assignment – we will have a one-on-one review later in the semester.

Name: _____

Year 1 Fall Semester			Year 1 Spring Semester		
Course	Credits	What Degree Requirement? (what?, list)	Course	Credits	What Degree Requirement? (what?, list)

Year 2 Fall Semester			Year 2 Spring Semester		
Course	Credits	What Degree Requirement? (what?, list)	Course	Credits	What Degree Requirement? (what?, list)

Year 3 Fall Semester			Year 3 Spring Semester		
Course	Credits	What Degree Requirement? (what?, list)	Course	Credits	What Degree Requirement? (what?, list)

Year _____ Fall Semester			Year _____ Spring Semester		
Course	Credits	Degree Requirement? (what?, list)	Course	Credits	Degree Requirement? (what?, list)

Year _____ Fall Semester			Year _____ Spring Semester		
Course	Credits	Degree Requirement? (what?, list)	Course	Credits	Degree Requirement? (what?, list)

Year _____ Fall Semester			Year _____ Spring Semester		
Course	Credits	Degree Requirement? (what?, list)	Course	Credits	Degree Requirement? (what?, list)

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Tyler Junior College

A#_____

Department of Engineering & Physical Sciences Date: _____

Student Information Sheet

Student Name: _____ DOB: _____
Last First MI

Local Address: _____
Street City, State, Zip

Local Phone: _____ Cell:_____

Permanent Address: _____
Street City, State, Zip

Permanent Phone: _____

Employer: _____
Name Contact Info

HS Math/Phys/Chem/Engr: _____

_____

Non-TJC College Math/Phys/Chem Engr: _____

_____

Concurrently Enrolled At: _____

_____

Major: _____

Expected to Transfer to: _____ Semester/Year: _____

Career Goals:

_____

Extracurricular:

_____

Scholarships:

_____

Was this face-to-face advising helpful to you? ☐ Yes ☐ No

(Use the back to provide additional information.)

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Familiarize w/Mindstorm

The purpose of this lab is to familiarize yourselves with the Lego Mindstorm Robot. This will be the means by which your design project will be powered and controlled.

Materials:

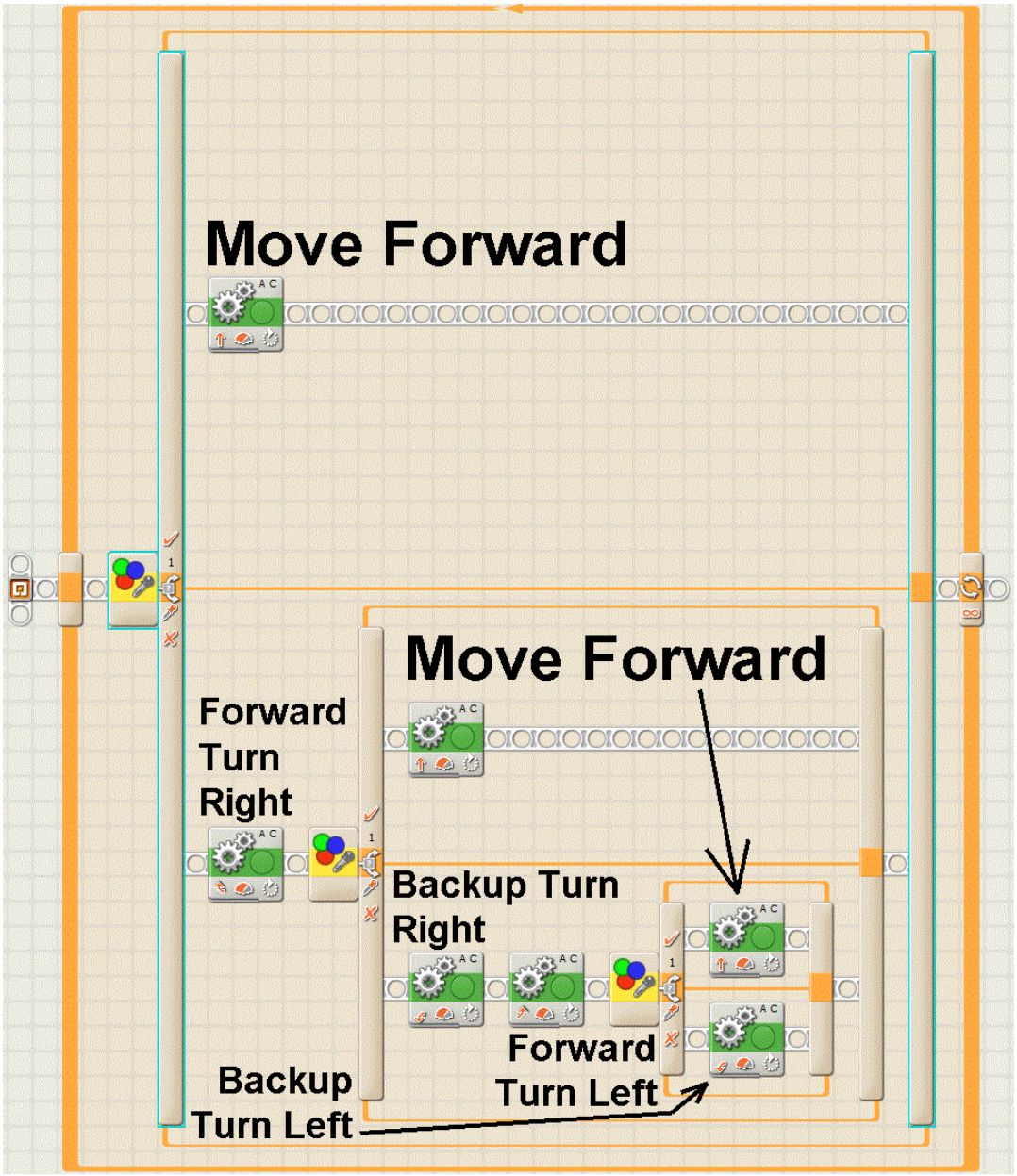
- Mindstorm Robot Kit & Instructions (Lego Site - building instructions are the property of the LEGO Group and may not be used for commercial use)
- Six Batteries
- Test Pad that comes with kit

Notes:

- A legible, albeit handwritten, report is due at the end of lab
- The Mindstorm robots run Labview - perhaps the most widely used control software. So, while you're getting an introduction to programming, you're getting it using something you'll most likely use in the future.

Procedure:

1. Build the Quick Start robot in the Lego instruction manual starting on p. 5. Be careful not to lose or break pieces - we want these robots to last several semesters.
2. After you finish you will need to attach the color sensor to the front. Think about how you will go about this. I'm not giving you instructions - this is something you have to figure out on your own.
3. Install the batteries (p. 22)
4. Connect the color sensor and connect the robot to the computer (pp. 18 & 19)
5. Launch the Mindstorm application on the computer.
6. Give a title to your program ("linefollow" suggested) and press go under "Create New Program"
    - Enter the following program. Note that all moves are 30°, the color sensor switch senses anything except white, and make sure you're sensing and driving the correct port (it matches how you connected your robot).



7. Download your program (p. 21 - down arrow)
8. Disconnect the USB cable
9. Place your robot on the black line of the test pad and press the orange button (start)
10. Record results in your lab notebook. How well did the robot follow the black line racetrack pattern? Since this is the first class you may record results on notebook paper THIS TIME ONLY.
11. Press the grey button below the orange button to stop the robot.
12. Correct program errors.
13. Reconnect the USB cable.
14. Repeat steps 7 to 13 as desired
15. Experiment as desired - see the Lego site for ideas
16. Record everything you did in your lab notebook.
17. Draft a report and **turn it in prior to leaving**.
18. In one week turn in a final report, using good business communication practices, on your activities of today.

Bridge Project

Engineering 1201

Acknowledgements: Dr. Ronald W. Welch, PE; Dr. Fredericka Brown; Dr. Hector Ochoa; and Dave Galley. This project borrows heavily from their work on engineering classes.

Objective: Your team will build a bridge using K-Nex, Lego Mindstorm components and popsicle stick. The bridge is required to hold 3 kg and span 50 cm. The bridge must detect oncoming waterway traffic, stop road traffic with gates, and provide a 50 cm wide by 15 cm high opening for ship traffic.

The load bearing components will be made out of popsicle sticks and glue ONLY. You may not use string, staples, or other materials to reinforce the joints. You must design a method to connect your load bearing components to the rest of the bridge, but be detachable for load testing. The span will be tested until destruction with bonus points awarded to the strongest load per weight bridge.

The design's performance is also judged by the time to execute a bridge opening and closing, energy efficiency, accuracy of control, user interface, footprint, peer review, clarity and completeness of presentation and documentation, and professionalism of the team. You are competing against other "companies" (groups) to win the contract.

- Up to 10% bonus is awarded for the highest strength to weight ratio bridge.
- Up to 10% bonus is awarded for “coolest” design
- Up to 10% bonus is award for best overall, that is, who is the contract awarded to. This measures professionalism, design, and cost factors.

You will have a two opportunities for major revisions of your projects. After each iteration your projects should improve and your final version should be dramatically improved over your original.

Specifications

Materials

- K'Nex components ***(May not be removed from college at any time)***
- Lego Mindstorm Kit ***(May not be removed from college at any time)***
- Optional "cable" if needed – string, fishing line, etc. However it must be used in cable stay configurations and not used as reinforcement of joints.
- Optional wood base (see below)
- Popsicle sticks and glue. You will be provided about 180 popsicle sticks at the first of the semester and they must be rationed to last the entire semester including all three destructive tests.
    - You may not buy more sticks – this is considered cheating. You are required to live within your budget.
- Other material
    - Not exceeding 10% of the project's weight (except base – it simulates ground)
    - Not exceeding $5.00 retail value (including base)
    - Anything above base will add to estimated cost at of popsicle stick cost
    - You are not allowed any additional materials for the span - popsicle sticks or cable stay (not reinforcing) cable only (you may purchase more glue)

- The bridge, when closed, may rest on the optional base
- ***If materials don't fit in box, they can't be stored at the college***

Test Load: 3+ kg mass

Performance

- Bridge opens and closes without unintended sideways or rotational motion
- Vertical opening of 15 cm or greater across entire span of 50 cm
  - A double capacity bonus (time cut in half) for a permanent vertical opening of 5 cm or greater across 25 cm of span. It considers that half of waterway traffic is 5 cm or less.
- Horizontal opening of 50 cm with 15 cm vertical opening the entire distance
- "Free standing" or anchored to base plate (plywood, etc.)
  - It must not damage K'Nex or Lego components
  - You may NOT use tape to anchor your bridge
  - Span must be detachable for load testing
- Attached to span in such a way that does not damage K'Nex or Lego components
- Roadway not to exceed 15% grade (8.5°) **at any point**
- Roadway must be wide enough for two hot wheels cars.
- Anytime a vehicle is above ground level, including the bridge deck, there must be a popsicle stick guard rail (about 5 mm high)
- You may use paper for road surface, however vehicle cannot fall through. Also there must be supports every car length along direction of travel and supports every car width perpendicular to the direction of travel.
- Test:
  - Detect oncoming waterway traffic
  - Stop bridge traffic
  - Opens only after bridge roadway traffic stopped which may be variable length of time
  - Time of opening variable and bridge lowered after water traffic has passed
  - Closes for variable length of time to check all conditions are safe
  - Allow bridge roadway traffic
  - Mechanical linkage to stop bridge traffic is unacceptable
  - Everything must be under software control

Performance Measures

- Time required to execute opening and closing
- Maximum load to weight ratio
- "Cost" analysis report of elevator based on costs of K'Nex and Lego pieces based on provided cost information
- Power consumption (motors required)
- Energy efficiency (number of motors * time)
- Final (up-to-date) Gantt & PERT charts ("Linear Responsibility Chart" and "Work Breakdown Structure" optional)
- Clear, sharp photographs of bridge as built for performance test
- Completeness, readability, and understandability of final trifold, report, and presentation
- Bonus for best strength to weight, best design, and best overall.
- Figure of merit (FOM) =
  [load (kg) + (3*span/(50 cm))]/[(time to raise and lower in sec)*(cost in M$)]

Additional Reporting Considerations

- Evaluate the strengths and weaknesses of your design
- Discuss why you chose your design
- Discuss why the contract should be awarded to your company

Documentation

- Each group member is to keep a notebook which will be reviewed each week
- Weekly activity report must contain copy of original timeline (plan) and current compliance to plan.
  - Deviations from plan must be completely explained and they better be good.
- Through the fifth week - planning and prototyping.
  - Complete bridge MUST be prototyped. You may NOT do only one section in the first 5 weeks. You must prototype all sections of the finished product.
- End of week 5:
  - **Bound planning report due** including discussion, detailed time line accounting for all activities of each group member, cost estimate (BOM), Figure of Merit (FOM – see above), and detailed multipage drawings.
    - Discussion to include full names, title, purpose, introduction, design strategy, discussion of progress and future plans, and any other information you feel is necessary. Be clear & concise, yet complete.
    - Detailed drawings due - may be hand drawn *with ruler* with hand printed, but legible, dimensions. Photograph is not a substitute.
      - All pieces must be accounted for
      - All dimensions must be called out
      - Orthographic projection acceptable (front, top, and side view)
      - Connectors may be represented by full or half round circles.
      - Linear pieces may be represented by broad lines
      - Multiple view are probably necessary
      - Multiple pages are probably necessary
      - Could somebody replicate building your bridge from the drawings?
  - First destructive test
- Sixth through tenth week - build, test, and second destructive test
- End of tenth week - **progress report, detailed drawings, and design improvement** due
  - **Bound progress report due** including discussion, GANTT & PERT, BOM & total cost estimate, Figure of Merit (FOM – see above), and drawings.
    - Discussion to include full names, title, purpose, introduction, design strategy, discussion of progress and future plans, and any other information you feel is necessary. Be clear & concise, yet complete.
    - Intermediate drawings due - must be B&W drawn with computer tool such as Excel's drawing tools, or Autocad or Solidworks. Photograph is not a substitute.
      - All pieces must be accounted for
      - All dimensions must be called out
      - Orthographic projection acceptable (front, top, and side view)
      - Connectors may be represented by full or half round circles.
      - Linear pieces may be represented by broad lines
      - Multiple view are probably necessary
      - Multiple pages are probably necessary
      - Could somebody replicate building your bridge from the drawings?
  - Second destructive test
- Second to last day of class (14th week) - measure performance of completed elevator

- Last day of class/lab - **trifold, bound report & oral presentation due** including cost analysis
  - Trifold - All points, but only highlights; abbreviated, but complete
  - Trifold to contain key summary information - don't cram report on to trifold
  - Thorough, bound report
  - Title, purpose, introduction, & discussion
    - Discussion to include full names, title, purpose, introduction, design strategy, discussion of adherence to plan and what you would do differently in the future, and any other information you feel is necessary. Be clear & concise, yet complete.
  - GANTT, PERT, BOM & total cost, performance measures (speed & load), & FOM
  - Final drawings due (same requirements as tenth week drawing)
  - Project must be constructed per drawing
  - Complete Bill of Materials (BOM) with cost analysis
  - Report on performance measures
  - Oral presentation to discuss key summary information, but presenter should be prepared to answer detailed questions. All members of the group are required to present - each shall discuss different aspect of project.
  - Final report to include all aspects of project - final drawings, final photograph, final performance, bill of materials including cost and cost total.
  - Peer grading

Helps

- Example: http://www.youtube.com/watch?v=5tMCk7bpdoY
- Mindstorm: User Guide (building instructions are the property of the LEGO Group and may not be used for commercial use) & Lego Site
- Reporting Guidelines
- More exhaustive, but good, style guide for engineering reports

Cost Estimate

Lego Component Costs	
Part	Cost
Rivets	$10 each
Connectors & plates	$20 per hole or stub
Wheel or pulley	$100
Tire	$100
Motor	$300
Controller	$1000
Axles	$80
Power supply	$200

K'Nex Component Costs	
Part	Cost
Rivets	$10 each
Small connectors & plates	$20 per hole or stub
Wheel or pulley	$100
Tire	$100
Large connectors & plates	$40 per hole or stub
Small diameter rods	$80
Large diameter rods	$200

Popsicle sticks	$720 per gram

- Popsicle sticks charged at same rate if used as structural or non-structural component and is about 10x the cost of Legos and K'Nex.
- Labor, R&D, software, etc. costs estimate to be twice materials cost
- Total cost = 3*materials

Elevator Project

Engineering 1201

Acknowledgements: Dr. Ronald W. Welch, PE; Dr. Fredericka Brown; Dr. Hector Ochoa; and Dave Galley. This project borrows heavily from their work on engineering classes.

Objective: Your team will build an elevator using K-Nex and Lego Mindstorm components. The elevator is required to lift 1 kg through a total vertical distance of about 16 cm with stops at 0 cm, 8 cm, and 16 cm. In other words, the elevator must controllably go to the first, second, or third floors. The design's performance is judge by the time required, energy efficiency, accuracy of control, user interface, footprint, peer review, and clarity and completeness of presentation and documentation. You are competing against other "companies" (groups) to win the contract - a 10% bonus will be awarded to the best elevator. Since this is competitive you should be cautious about sharing information with the other "companies."

In real engineering sometimes you only have one shot, however in this class we intend to learn from our mistakes and you will have a couple opportunities for major revisions of your projects. After each iteration your projects should improve and your final version should be dramatically improved over your original.

Specifications

Materials

- K'Nex components
- Lego Mindstorm Kit
- "Cable" - monofilament fishing line
- Plywood base optional (see below)
- Other material -
    - Not exceeding 10% of the project's weight, and
    - not exceeding $5.00 retail value

Test Load: 1 kg mass (or less) on hanger - 11 cm high & 5.5 cm diameter. Build your elevator to accommodate as much load as possible up to 1 kg. Load to be lifted using a hook (a platform lift is optional, but results in additional points awarded).

Performance

- Lifts mass without horizontal or rotational motion.
- Vertical rise of 16 cm with full load - additional points for higher rises and/or higher loads
- "Free standing" or anchored to base plate (plywood) that you provide in such a way that does not damage K'Nex or Lego components
- Test under operator control:
    - Under load measure time to go to second story & stop
    - Return to ground floor (first story)
    - Go to third story & stop
    - Return to ground floor
    - Go to second story & stop
    - Go to third story & stop
    - Go to second story & stop
    - Return to ground floor

Documentation

- Lab notebook - weekly
- Through the fifth week - planning and prototyping
- End of week 5 -
    - **Planning report due** including GANTT and PERT charts and cost estimate (BOM)
    - Prototype drawing due - may be hand drawn *with ruler,* photograph is not a substitute
    - Prototype performance measure (test time and FOM-figure of merit per below)
- Sixth through tenth week - build and test
- End of tenth week - **progress report, drawing, and design improvement** due
    - Title, purpose, introduction, & discussion
    - Drawing in B&W using paint, excel, or CAD program - not photographed or hand drawn
- Connectors may be represented by full or half round circles.
- Linear pieces may be represented by broad lines
- Multiple view are probably necessary
- Multiple pages are probably necessary
    - GANTT, PERT, BOM, Total Cost, Time, & FOM
- Second to last day of class (14th week) - measure performance of completed elevator
- Last day of class/lab - **trifold, report & oral presentation due** including cost analysis
    - Trifold - All points, but only highlights; abbreviated, but complete
    - Trifold to contain key summary information - don't cram report on to trifold
    - Thorough, bound report
    - Title, purpose, introduction, & discussion
    - GANTT, PERT, BOM, Total Cost, Time, & FOM
    - Final drawing due (same requirement as tenth week drawing)
    - Project must be constructed per drawing
    - Bill of materials with cost analysis
    - Report on performance measures
    - Oral presentation to discuss key summary information, but presenter should be prepared to answer detailed questions. All members of the group are required to present - each shall discuss different aspect of project.
    - Final report to include all aspects of project - final drawings, final photograph, final performance, bill of materials including cost and cost total.
    - Peer grading

Performance Measures

- Time required to lift
- Maximum load
- "Cost" analysis report of elevator based on costs of K'Nex and Lego pieces based on provided cost information
- Power consumption
- Energy efficiency (ratio of mechanical delivered to electrical energy consumed).
- Final (up-to-date) Gantt & PERT charts ("Linear Responsibility Chart" and "Work Breakdown Structure" optional)
- Clear, sharp photographs of elevator as built for performance test
- Completeness, readability, and understandability of final trifold, report, and presentation
- The best overall project will be awarded 10% bonus - of points

- Figure of merit = [load/(time*footprint*cost)]
- Floor bonus = 10% per floor (1.25%/cm)
- Load bonus = 25% per kg

Additional Reporting Considerations
- Evaluate the strengths and weaknesses of your design
- Discuss why you chose your design
- Discuss why the contract should be awarded to your company

Helps
- Example: http://www.youtube.com/watch?v=5tMCk7bpdoY
- Mindstorm: User Guide (building instructions are the property of the LEGO Group and may not be used for commercial use) & Lego Site
- Reporting Guidelines
- More exhaustive, but good, style guide for engineering reports

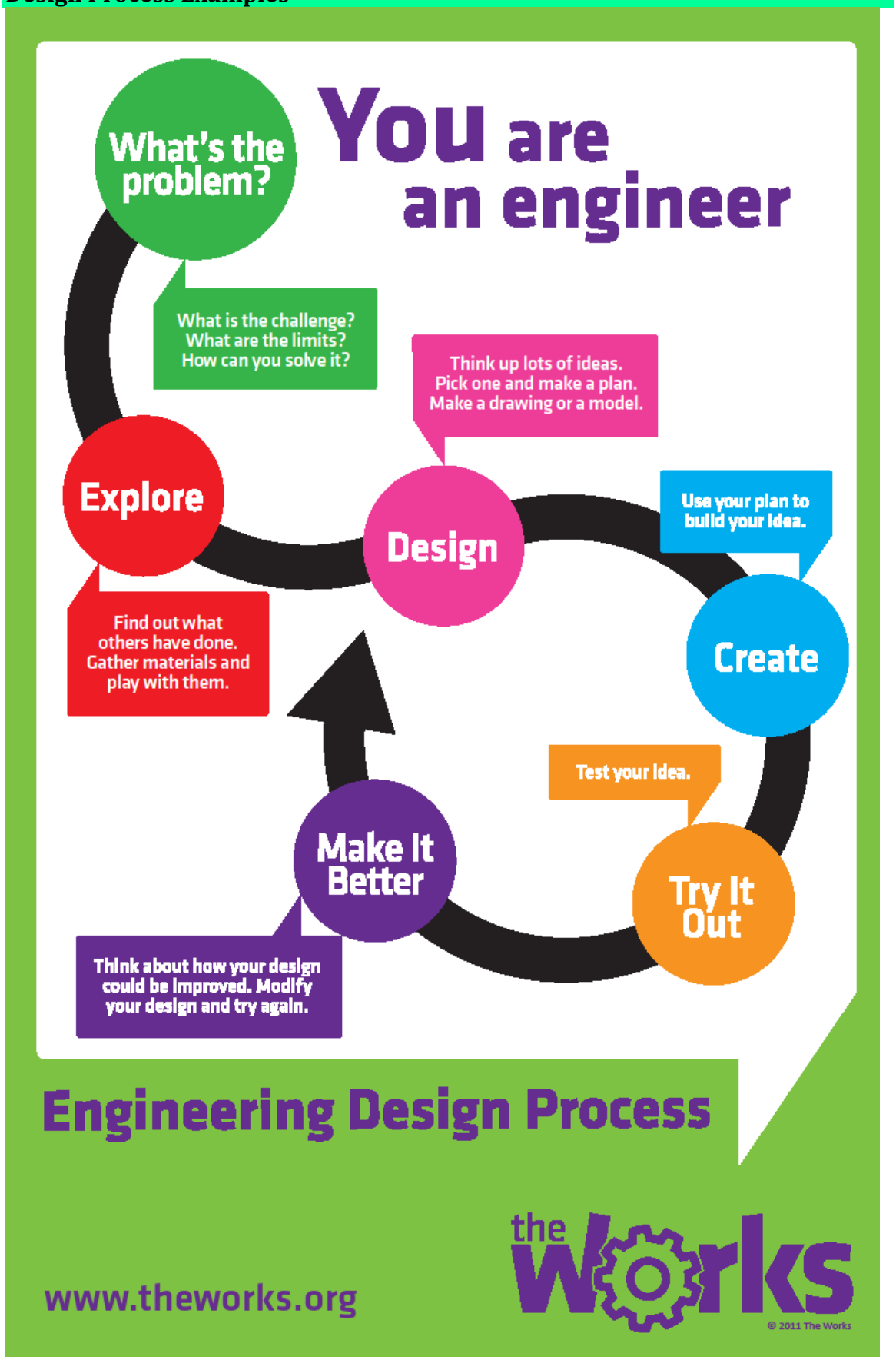
Cost Estimate

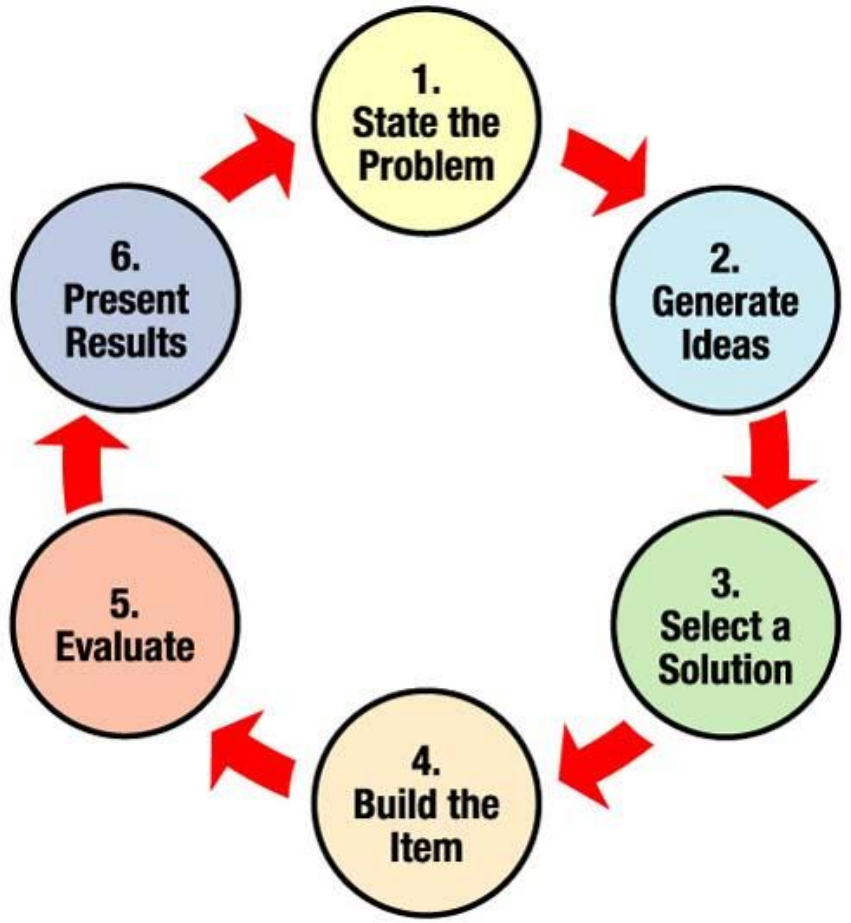
Lego Component Costs	
Part	Cost
Rivets	$10 each
Connectors & plates	$20 per hole or stub
Wheel or pulley	$100
Tire	$100
Motor	$300
Controller	$1000
Axles	$80
Power supply	$200

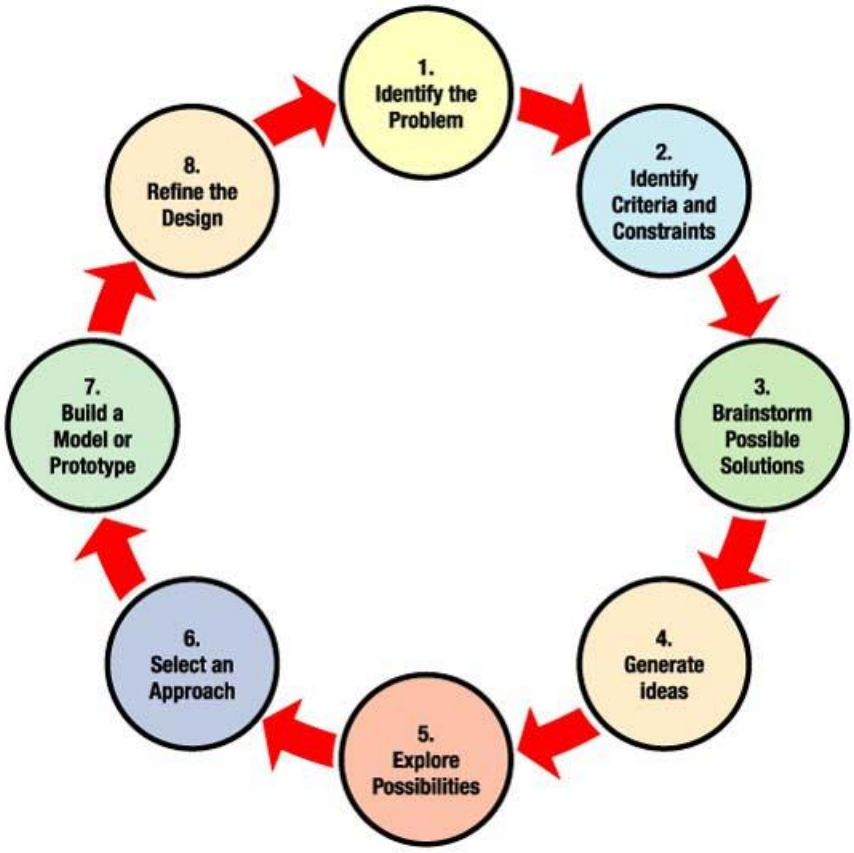
K'Nex Component Costs	
Part	Cost
Rivets	$10 each
Small connectors & plates	$20 per hole or stub
Wheel or pulley	$100
Tire	$100
Large connectors & plates	$40 per hole or stub
Small diameter rods	$80
Large diameter rods	$200

- Labor cost estimate equals twice materials less motor, power supply, and controller divided equally between construction cost and software development cost.
- Cost of supporting structure (building) = footprint in cm^2 * $150
- Total cost = materials + labor + infrastructure (building)

Design Process Examples

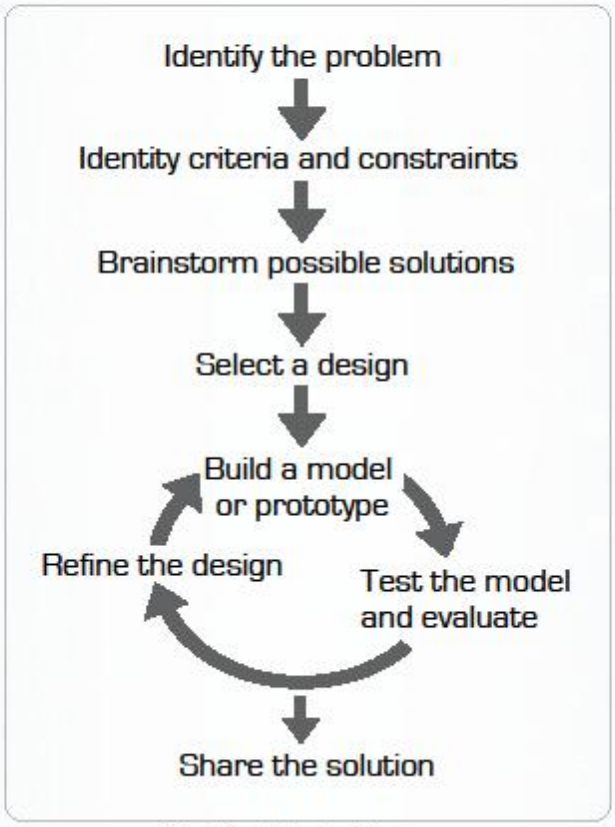



1.
State the Problem
2.
Generate Ideas
3.
Select a Solution
4.
Build the Item
5.
Evaluate
6.
Present Results


1.
Identify the Problem
2.
Identify Criteria and Constraints
3.
Brainstorm Possible Solutions
4.
Generate ideas
5.
Explore Possibilities
6.
Select an Approach
7.
Build a Model or Prototype
8.
Refine the Design

Design Process

Middle School and High School Design Packet



Graphic of Design Process

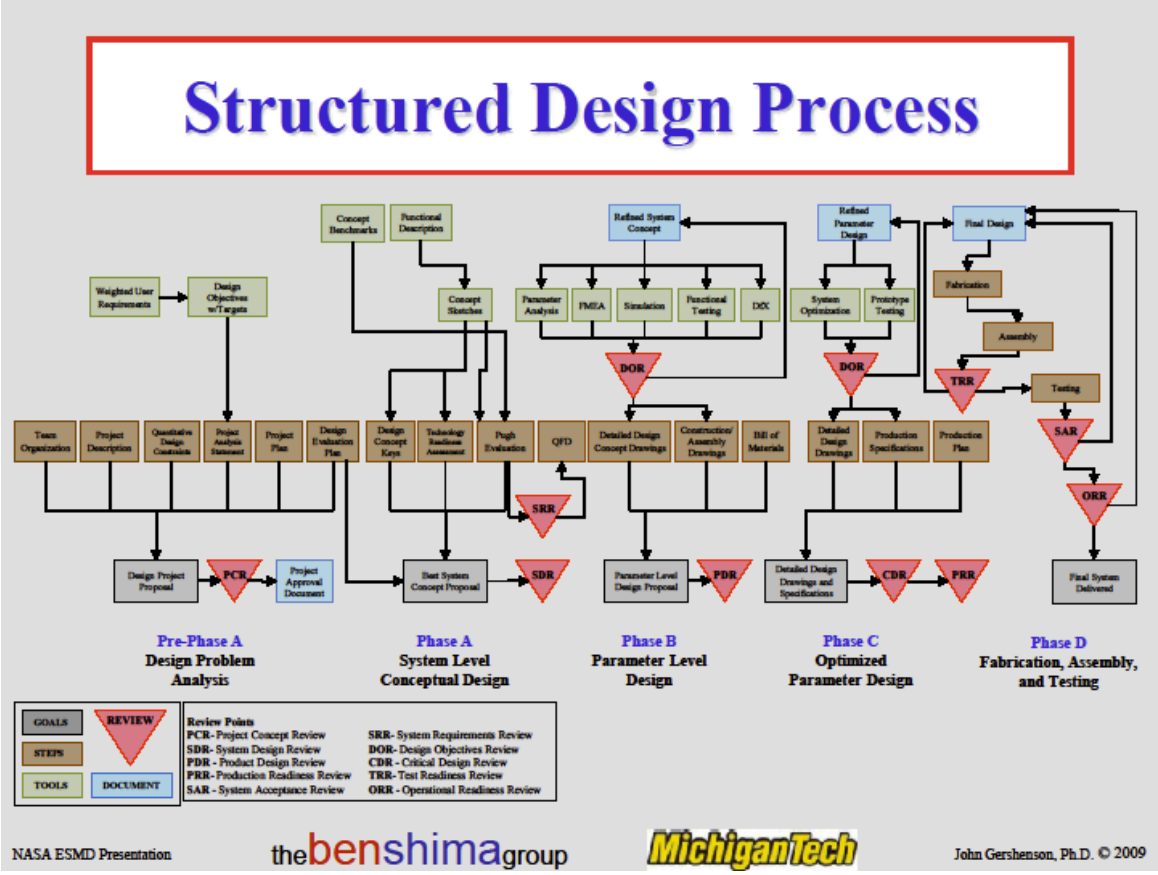
Steps of the Design Process

1. Identify the problem.
2. Identify criteria and constraints.
3. Brainstorm possible solutions.
4. Select a design.
5. Build a model or prototype.
6. Test the model and evaluate.
7. Refine the design.
8. Share the solution.

2

The 12 engineering design steps as they are applied in this unit are as follows:

1. Defining a problem
2. Brainstorming
3. Researching and generating ideas
4. Identifying criteria and specifying constraints
5. Exploring possibilities
6. Selecting an approach
7. Developing a design proposal
8. Making a model or prototype
9. Testing and evaluating the design using specifications
10. Refining the design
11. Creating or making the final solution
12. Communicating the processes and results



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Design Process

Design a swing

_____, _____, _____

_____, _____

Names – no more than 5 or less than 3. When it gets to 6 split into two groups

This in-class exercise is designed to lead you through the design process using a simple example - a child's swing. A more thorough analysis is required for your semester long project. NASA has done a lot on this issue and developed guidelines depending on the level of people involved. Here's an example aimed at lower grades (local link), here's a middle school to high school packet (although good for college as well & local link), and here's a capstone (college Senior or professional) example.

What is the Design Objective? What's important - cost, safety, high performance, etc.?

What is the Design Strategy?

What information is necessary?

Make a first cut at the design - draw a good sketch below or on the back of this paper. For this exercise we won't go through the rest of the cycle of prototyping, documentation, testing, revision, final test, and marketing.

Trade this page with another group. What are the names of other group members?

Second group, review this project. On a scale from 1 to 3 rate this project with 1 being poor, 2 average, and 3 good. Rate and comment on the overall objective:

Rate and comment on the design strategy:

Did the group provide sufficient information?

Is the first cut at the design clear, understandable, efficient, and effective?

Other comments?

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After the Brainstorming

Your book (*Design Concepts for Engineers* by Horenstein) has a very good discussion of brainstorming, however the question arises, what next? We need a means to refine the host of ideas generated in brainstorming.

First, let's review brainstorming. The key principle is getting everything on the table. No holding back, no boundaries, no criticizing, no dismissing, no limit, no restrictions, & no shame.

The next step, then, is to sift through the ideas generated during brainstorming and prioritize. The easiest way to illustrate this is with a T chart. You may have heard of this. Say you're trying to decide to go to college at UTT vs. TJC. You make a T chart as follows:

factor	UTT	TJC
cost	-	+
locale	0	0
transfer	+	-

You'll notice the reason it's called a T chart is it looks like a T. At first glance it looks like 6 of one, half dozen of the other. TJC is less expensive, but the transfer hassle is eliminated. However if you're pressed for cash, you might favor TJC, and if money is no object then you'd favor UTT. **Not all factors are equal!**

The way to handle this is weight factors. Teachers do this all the time. Homework is worth 15%, quizzes 10%, etc. Let's think how this works designing a car. Gas prices are skyrocketing and so fuel economy is critical, but comfort, amenities, passenger room, and cargo space are also important. A "tradeoff" chart might look like this:

factor	weight	SUV	Van	Minivan	Sedan	Compact
mileage (mpg)	6	15	15	20	30	40
passengers	30	6	9	8	6	5
cargo (cu ft)	1	250	200	150	50	25
comfort (1-5 scale)	6	3	3	4	5	0
extras (1-5 scale)	6	3	3	4	5	3
Total		556	596	558	470	433

Let's analyze the weights (not pounds - tradeoffs) on the table. One passenger consumes 30 cu ft of space - so the weight is 30 on the passenger row and 1 on the cargo space row. If you're driving cross-country a sedan and van are roughly equal leading to 3 passengers is worth 15 mpg - a 5 to 1 ratio. 3 passengers * 30 = 15 mpg * 6. Comfort and extras are down in the priority list although it would be quite uncomfortable to drive

cross county in a compact. Let's say a comfort level of 5 is worth 5 mpg and extras (DVD, radio, etc.) is also a 1 to 1 correspondence with mpg. So we complete our table.

To get the totals we multiply weights times value and sum columns. For example, the SUV total would be 6*15+30*6+1*250+6*3+6*3=556, The compact would be 6*40+30*5+1*25+6*0+6*3=433.

Based on this analysis the standard van wins. However usually we don't carry 9 people - families are generally closer to 4 people. However for baseball, football, or basketball teams it's a great option. Also we don't use all the cargo room. Our weighting would need to change depending on how we used the vehicle. Minivans are great for families of 4 who need the flexibility of extra cargo at times and several people at other times. For a city commuter car nothing else counts except mpg and small cars get around easier in big cities. In this case you'd choose the compact car and may even gravitate toward a motorcycle or bicycle.

Admittedly this table is just a rough idea of how this procedure works and it's imprecise. Expect teams to debate how much weight should be given to each factor.

Now you try this. Get in your groups, pretend you're going to be roommates going in on an apartment, brainstorm (follow the book's advice), devise a tradeoff table, and that's what you'll turn in on a separate page. Use this guide for prices: Basic 1 bedroom $500 per month, moderate 1 bedroom $600, luxury 1 bedroom $700, basic 2 bedroom $700, moderate 2 bedroom $800, luxury 2 bedroom $900, etc. Note $200 per mo. added for each bedroom. Ignore commuting costs - in Tyler you can get pretty much what you want close to work. In other locales you would need to consider this.

SOLVE & Teamwork

In a modern work environment, we do not work in isolation. We must interact and get along. Here are a few pointers. Also see 7 Habits of Effective Science Students and How to Flunk.

Individual Problem Solving:
For individual problem solving we strongly, strongly encourage the use of the SOLVE 5-Step Problem Solving method. See the SOLVE page, but in summary:

1. **S - Sketch:** **Sketch, draw a picture, understand the problem**
2. **O - Organize:** **Organize, write down known and unknown quantities**
3. **L - List:** **List relevant equations, determine which are applicable**
4. **V - Vary:** **Vary, rewrite, and transform equations to express unknown quantity in terms of known quantities**
5. **E - Evaluate:** **Evaluate expressions, Plug in Numbers, evaluate to determine if answer makes**

We will be using this throughout the course.

Group Problem Solving:
This also works for group problems solving. The same reason the SOLVE 5-Steps help individuals wrap their heads around a problem, it helps communicate your reasoning to others.

Tolerating Frustration:
Quantitative reasoning can be frustrating. A large number of steps and if you make a mistake on any one step you will get a wrong result. That's why we need to tolerate frustration to succeed in quantitative disciplines.

Working with Others:
There are many classes on working together offered by our college and other colleges. All of these help defuse emotional tensions and help us work with other, disparate people. Everybody has a unique and valuable perspective we need to appreciate to come to the best answers. We need to respect others opinions and interact civilly in order to WORK together.

Brainstorming:
One (and there are many) technique is brainstorming. List ideas, any idea. Don't tease people for bad ideas - bad ideas are OK, we'll eliminate them later. Get everything on the table so we can sort through them and find the good ideas. We want the team members to feel comfortable saying something.

Labs as practice for team building:
We will do labs throughout the quarter. Research has established that groups of 3 or 4 work best and sometimes it is necessary to make a pragmatic decision. If we have eight sets of lab equipment and 32 students, it's clear that we will have lab groups of four

people. Part of the purpose of labs is practicing productive, respectful, supportive group interaction. Here are a few guidelines:

1. Be on time!
2. Study the lab before arriving at class!
3. Have all group members practice doing all portions of the lab. If you're doing a measurement, have all group members practice doing the measurement. When assembling equipment, have all group members participate in assembly so everybody understands how the experiment was set up.
4. Avoid one or two people dominating the group. It's important everybody participates.
5. If your group decides to assign "jobs," rotate those jobs each week. For example, avoid having the same person always being the data recorder.

Explain your reasoning:

You really learn something when you can explain it to somebody else. I expect the stronger students to explain their reasoning to students who don't understand. And I expect students who don't understand something to ask. And I expect respect for those questions. We close the cycle of learning when you can explain your reasoning.

SOLVE Problem Solving

Revised from Physics 170 text by Bob Abel, et al. Also see 7 Habits of Effective Science Students and How to Flunk.

In Summary:

1.	**S - Sketch:**	**Sketch, draw a picture, understand the problem**
2.	**O - Organize:**	**Organize, write down known and unknown quantities**
3.	**L - List:**	**List relevant equations, determine which are applicable**
4.	**V - Vary:**	**Vary, rewrite, and transform equations to express unknown quantity in terms of known quantities**
5.	**E - Evaluate:**	**Evaluate expressions, Plug in Numbers, evaluate to determine if answer makes**

SOLVE Five Step Method In Detail:

THE FIVE STEP METHOD OF PROBLEM SOLVING

1. S - Sketch: READ THE ENTIRE PROBLEM CAREFULLY AND MAKE A SKETCH

Read through the entire problem completely before you start to write anything down. A sketch of the problem situation will help you to clarify the ideas of the problem. If you can't visualize the situation, you might be missing some important concepts.

2. O - Organize: LIST THE GIVEN INFORMATION AND IDENTIFY THE UNKNOWN QUANTITY ASKED FOR IN THE PROBLEM.

Write down each magnitude (number and units) that is given and identify it with the appropriate letter. For example, " a time of six seconds" is listed as "t = 6 sec".
It is important to use the letter symbol that will appear in the equations. For example, if a problem asks you to find "how long it takes" for an event to occur, you would write "t =?". Be sure to understand what the letter means and write it down to help you remember. For example, "t = 6 sec: t is the time it takes for the object to travel the distance."

3. L - List: LIST EQUATIONS, SELECT THE EQUATION THAT RELATES THE UNKNOWN QUANTITY TO THE GIVEN INFORMATION.

For example, if you know the velocity (v) of an object and the distance it has traveled (d), and you wish to find the time required to travel that distance (t), you would choose the equation that uses all three of these variables: $t = \frac{d}{v}$.

4. V - Vary: REVISE, REWRITE, AND TRANSFORM THE EQUATION, IF NECESSARY, TO SOLVE FOR THE UNKNOWN QUANTITY. THE REVISED EQUATION IS THE WORKING EQUATION.

The unknown (in this case, t) should appear alone on either the left or right side of the equal sign in your working equation. In the example above, if the unknown was the velocity, the equation would be rewritten to read: $v = \frac{d}{t}$.

5. E - Evaluate: SUBSTITUTE THE KNOWN INFORMATION IN THE WORKING EQUATION, INCLUDING ALL UNITS. SOLVE THE EQUATION, INDICATING THE CANCELLATION OF UNITS, AND CIRCLE YOUR ANSWER.

If you are solving for the velocity, the distance is 12 meters ("d = 12 m"), and it took 6 seconds ("t = 6 s"), then we would write (after "$v = \frac{d}{t}$"), $v = \frac{12\ m}{6\ s} = 2\ \frac{m}{s}$. The units combine (and can cancel) just like numbers. Notice that "meters per second" is a correct unit for velocity. EVALUATE your answer to see that it has the correct units. For example, if you find that the weight of an object is in units of "square feet", then an error has occurred. Also, EVALUATE the magnitude of your answer; if it is obviously physically impossible, go back and look for an error. For example, if you find the speed of a car to be 4000 mph, the answer is not reasonable. Make sure you circle your answer to avoid confusion.

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Applying SOLVE

_____, _____, _____

_____, _____

Names – no more than 5 or less than 3. When it gets to 6 split into two groups

Assume the population of a large city like New York City is about 2×10^6 people, with about 1.59 people per household. Approximately 1 household in 17.9 has a piano. The piano keyboard has about 64 notes (8 octaves) with about 2 strings per note. A piano should be tuned once per year (365.25 days). A piano tuner can tune about 3 pianos per day. And, finally, piano tuners work 247 days per year. How many piano tuners are there in New York City? Note: This was one of Prof. Fermi's famous party questions.

Apply the SOLVE method to analyze and solve this problem.

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Estimating

The first step in a cost analysis is a BOM (Bill Of Materials). It's a table with several columns that can be done in Excel. First column is item number, second column description of item, third column price or cost for each piece, fourth column is quantity, and last column is the quantity times price for each part. The last row, last column is the total price or cost. Some organizations also include other information such as sku, vendor, etc., and sometimes an organization just wants to know what it takes to build something - not the cost. The ingredient list in a cooking recipe is an example of a BOM without cost information. While the leading columns may vary between organizations, the last three columns (of a costed BOM) follow the convention of price per part, quantity, and total (price per part times quantity). Let's show an example for a hot wheels car.

Item #	Description	Price Each (cents)	Quantity	Row Total Price (cents)
1	Body	5	1	5
2	Chrome plated under carraige	6	1	6
3	Front Windshield	2	1	2
4	Rear window	2	1	2
5	Left and Right Front Side Windows	1	2	2
6	Left and Right Rear Side Windows	1	2	2
7	Interior	4	1	4
8	Axles	2	2	4
9	Wheels	2	4	8
			Total	35

Assignment: Next week turn in this form of BOM analysis for your elevator. Some of you have already cast your analysis in this form so you can just copy what you've done previously. For others you'll need to revise your analysis.

Labor Cost

Different organizations use different techniques to determine labor costs. A roofer or flooring company may charge per square foot installed. Auto mechanics look up the time it requires to do a job and multiply that by their labor rate. Sometimes labor is estimated by a factor multiplying the materials cost - that's how we're estimating labor in our elevator project. Sometimes an exact time analysis is done and then multiplied by the labor rate.

With lots of experience an organization can accurately estimate labor cost. The first time you do something, however, it's difficult to estimate labor. The Boeing 787 is a good example of this. It used lots of new technology, but this created lots of problems that

delayed it by three years. Often organizations will build in contingency plans in case things don't work out according to an ideal plan.

How to Determine Payoff

Let's say if you retooled a plastic molding tool at a cost of $10,000, you could save a couple cents per car ($0.02). How many cars would you have to build to equal this cost? Answer is simply $10,000/$0.02 or 500,000. The best estimate I could find is approximately 500 million are sold each year. So the payoff is 1/100th of a year or 3.65 days - very fast payoff and well worth the expense.

For the sake of example let's say a smaller quantity, 50,000 are sold each year so simplistically it would take 10 years (500,000 to pay off divided by 50,000 sold per year) for this to pay off. Is it worth it now? If you had to retool every 5 years, no, it would not be worth it. If you retooled every 20 years then, probably, it would be worth it.

Why probably? It's because you have to have a basis of comparison and a common basis of comparison is how much would that money earn in today's dollars if invested. If you put that $10,000 in an investment (the company stock, for example) that earned, for example, 4% (annualized adjusted for inflation) interest, would you make more money than if you bought new tooling? Here's how that analysis works, however, be warned - the math is beyond the requirements of this class. Just realize this is what the CFO (Chief Financial Officer) is doing when they decide whether or not to spend money on this new tooling.

Also we must account for inflation. Today's dollars are (generally) worth more than tomorrow's dollars. If we put a lump sum in the investment the rate of return is the APR (Annualized Percentage Rate) less the inflation rate (R_i). Let's call this rate of return *R*, and for the sake of example let inflation be 4% per year, and APR at 8% per year. So, in our example, *R* is 4%. Here's the formulas:

$$FV = PV(1 + R)^T = PV\, e^{R'T} \approx PV\, e^{RT}$$

PV is the present value ($10,000 in our example), *FV* is future value, *T* is number of years, and R_r' is an adjusted rate for continuous investment (a good approximation you can do on a scientific calculator). R' is close to *R* and they are connected through the formula:

$$R' = \ln(1 + R)$$

In our example then R' = 3.9221%.

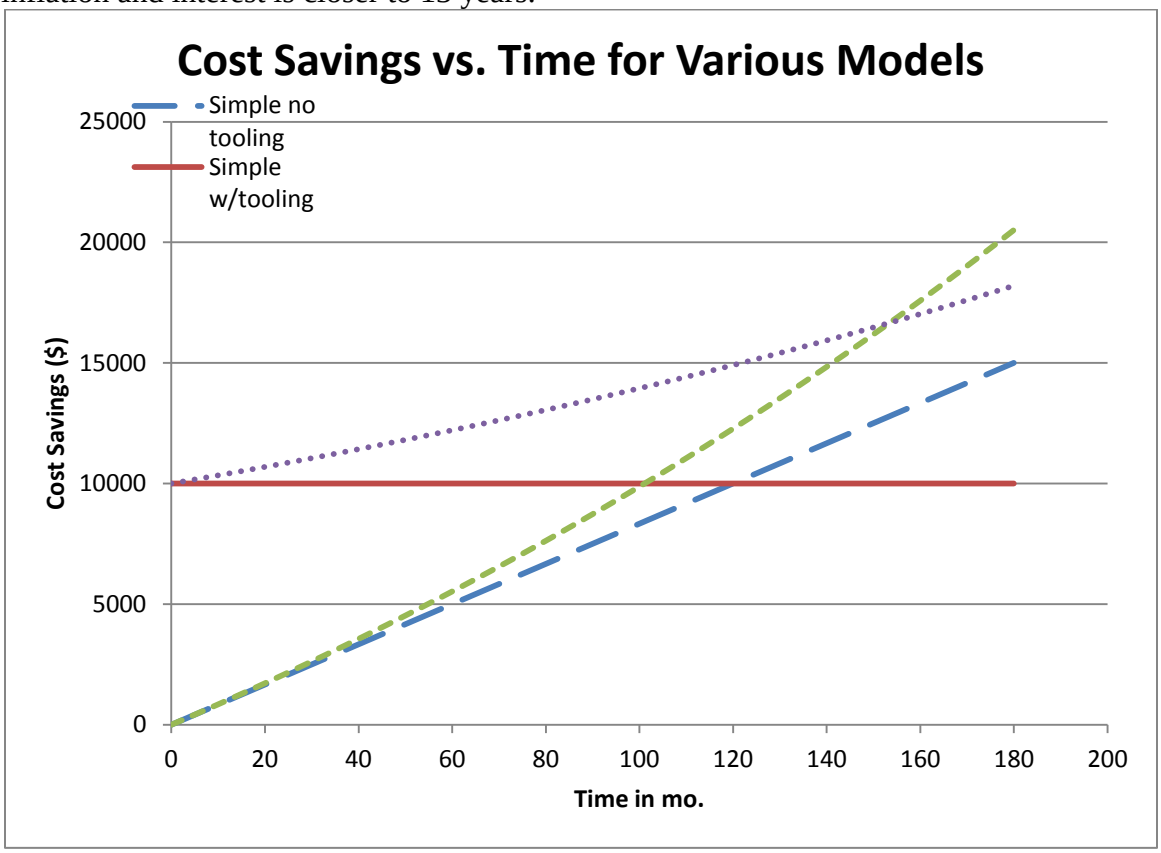
To complete the analysis we compare this to how much we would make by implementing the tooling, but we don't get our money back quickly - we get it back 2 cents at a time (PMT=2¢). The formulas for this are ordinary annuity formulas (like a mortgage), this formula adjusts for inflation, and R_s is simple interest (APR = $(1+R_s/m)^m$ where m is number of payments per year). Without adjusting for inflation:

$$FV = m\, PMT \left(\frac{\left(1 + \frac{R_s}{m}\right)^{mT} - 1}{R_s} \right) \approx m\, PMT \left(\frac{e^{R_s T} - 1}{R_s} \right)$$

and adjusting for inflation:

$$FV = m\,PMT\left(\frac{\left(1+\frac{R_s}{m}\right)^{mT}-1}{R_s}\right)(1+R_i)^{-T} \approx m\,PMT\left(\frac{e^{RT}-e^{-R_iT}}{R_s}\right)$$

where R_i = inflation rate = 4%. The next chart plots these formulas vs. time in months. The main effect is that the simple (no interest) payback model is off – the simple model predicts payoff too soon. Simple model predicts 10 years where the model including inflation and interest is closer to 13 years.



The Price of Risk

We didn't even consider a risk analysis. If a business spends $10,000 today, it depletes its bank account, and then if sales drop it might go out of business. In business this is called overextension. Businesses try to expand too fast, spend a lot of money, then can't make sales to cover these expenses, and go bankrupt. A good risk analysis assesses the probability of bankruptcy if an expenditure is made, for example, an expansion, new store, etc. So if your employer's cash flow is in trouble, you might not get the retooling.

Cost of Ownership (COO)

There's a more complex analysis called COO (Cost of Ownership). If you buy a car you have to fuel it, change the oil, change the timing belt, replace tires, replace batteries, etc. In our simple model we assumed no cost of maintenance. In reality there is a cost of maintenance. Simplistically you can think of COO as a one-time up front cost plus maintenance cost per time. In addition there may be a consumable cost (for the automobile metaphor that would be gas) that for every unit delivered (mile driven) there

is a cost. The complexity increases, but it begins with the basic principles studied earlier in this article.

Summary

This introduces you to the thinking behind the business decisions whether or not to replace tooling, expand, etc. Hopefully in your careers you can understand how your CFO and CEO are making their decisions and better argue for or against a proposed course of action. Later we'll study business communication - the art of tactfully, yet directly, succinctly, and effectively, communicating your arguments.

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Which Way Does the Moon Move?

_____, _____, _____

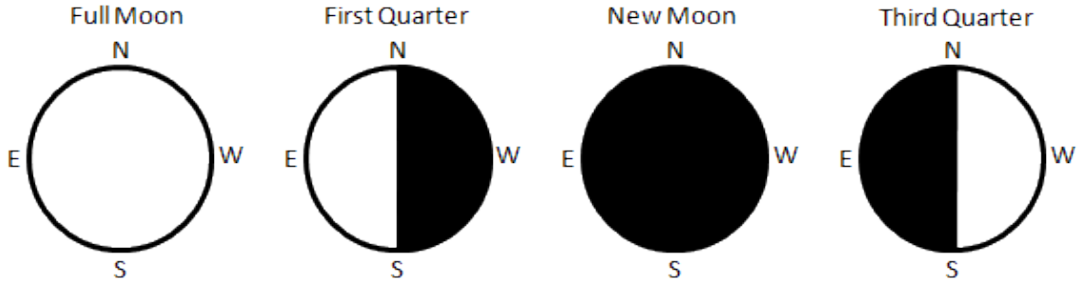
_____, _____

Names – no more than 5 or less than 3. When it gets to 6 split into two groups

The Sun and the Moon are the two astronomical objects that are most evident to us. In this assignment we seek to answer the direction the Moon moves around the Earth.

Equipment: Your eyes and brains and your teammates

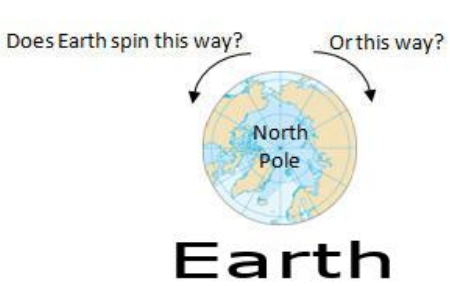
Procedure: Over the period of this class, observe the moon nightly (or daily). Work as a team – if one person forgets to observe, another teammate can pick up the slack. Discuss this with each other. Sketch the image of the moon - be sure to label North, South, East, and West. The four most common phases follow:

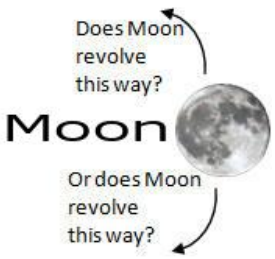


North, South, East, and West are the direction you would observe when laying on your back with your head to the North and looking UP into the sky. A regular map is the view looking DOWN at the Earth. We are flipped 180° from what we were used to.

In addition to phase, report Moon rise and Moon set. You may estimate this. For example, if at 8 pm the moon is halfway through the sky, Moon rise was about 6 hr before that or 2 pm and Moon set is about 6 hr after that or 2 am. Fill in the table at the end for at least one full cycle. A few days before the New Moon, the Moon sets shortly before the Sun and is difficult to see near sunset, but can be seen shortly before sunrise. After the New Moon it is easy to see after sunset, but after the First Quarter it rises past midnight. You may skip days if inclement weather prohibits observation, but do the best you can.

Required Analysis & Conclusion: Explain, at a 5th grade level, the direction (clockwise or counter-clockwise) the Moon revolves around the Earth and how you deduced this from observation of phases and Moon rise and set. *Observations may be done as a group, but your explanations must be turned in individually.* Sketch the relationship of the Sun, Earth and Moon in for the four major phases of the Moon. Show the view looking down at the North pole, the view from Earth, the direction the Earth is rotating, and the direction the Moon is revolving.





Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Sketch	Sketch	Sketch	Sketch	Sketch	Sketch	Sketch
Moon rise:	Moon rise:	Moon rise:	Moon rise:	Moon rise:	Moon rise:	Moon rise:
Moon set:	Moon set:	Moon set:	Moon set:	Moon set:	Moon set:	Moon set:
Sketch	Sketch	Sketch	Sketch	Sketch	Sketch	Sketch
Moon rise:	Moon rise:	Moon rise:	Moon rise:	Moon rise:	Moon rise:	Moon rise:
Moon set:	Moon set:	Moon set:	Moon set:	Moon set:	Moon set:	Moon set:
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