Engineering the Future
Science, Technology, and the Design Process

Engineer's Notebook: Project 2.0

Design a Building of the Future

National Center for
Technological Literacy®

Museum of Science, Boston

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National Center for Technological Literacy (NCTL)
Engineering Education for All

The goal of the NCTL is to foster appreciation and understanding of the human-made world by infusing technology and engineering into K–12 schools and museums nationwide. By applying science and mathematics as well as engineering processes, children and adults will solve real-world problems and learn about the creation and implications of technologies.

For more information, visit www.nctl.org.

Project 2.0

Design a Building of the Future

Birds use twigs, straw, and other materials to weave nests. Bees produce their own wax to construct hives for storing honey. Ants use the Earth itself to build underground cities. Although animals produce amazingly complex living spaces, they have little choice about the materials they use and the structures they build. Humans, on the other hand, make a vast number of choices when they choose materials and design buildings for a wide variety of purposes, such as homes, schools, factories, power plants, gymnasiums, garages, theaters, and many others. The world of the 21st century will be shaped in large part by the buildings that are designed by architects and engineers; the quality of our world will depend on their knowledge and problem-solving abilities.

In Project 2.0, you will design a building of the future. You may think of a building as a large organizer of human tasks, with specific places to cook, eat, sleep, watch television, brush your teeth, or converse with other people. If it's a place of work, your building may also have places to produce and sell products or work at computers or other complex machinery. But before you begin to design your building, you will also need to think like a structural engineer. The tasks that make up Project 2.0 will help you do that, so at the end, you will be able to design a building to help improve people's lives in the 21st century.

- 2.1 Define the Problem
- 2.2 Identify the Loads the Building Must Support
- 2.3 Use Failure Analysis to Design a Safer Building
- 2.4 Test Construction Materials for Strength
- 2.5 Describe Mechanical Properties of Materials
- 2.6 Experiment with Concrete
- 2.7 Make Your Building Energy Efficient
- 2.8 Make a Scale Drawing of Your Building Design
- 2.9 Design a Building of the Future!

Name ______________________________

Teamwork

Engineers most often work in teams. A team shares resources, information, and talent to develop the best solutions to problems. In this course, you will frequently work as a member of a team. According to working engineers, you will be expected to:

1) Organize your team by designating co-leaders and specialists for critical objectives.

2) Apply the seven teamwork behaviors listed below, amending them as agreed.

3) Jointly agree upon your mission, objectives, and motivation to accomplish the challenge.

4) Schedule your team effort by setting a time line of tasks, and delegate responsibilities.

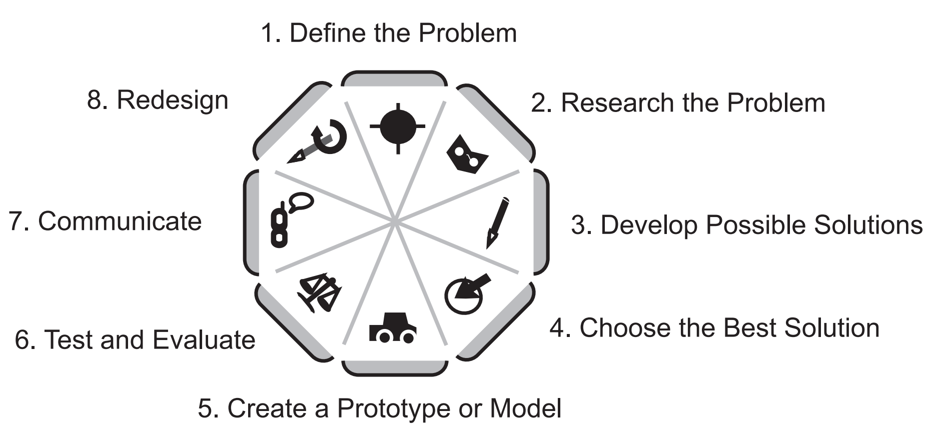
5) Carry out your plan on schedule, documenting procedure and results as you go.

6) Prepare for presentation of your conclusions and results.

There are seven behaviors that should be displayed by members of a team. They are the following:

Helping, offering assistance to others.	**Questioning,** interacting, discussing, and posing questions to all members of the team.
Listening, working from each others' ideas.	**Respecting,** encouraging and supporting the ideas and efforts of others.
Participating, contributing to the project.	**Sharing,** offering ideas, and reporting findings to each other.
Persuading, exchanging, defending, and rethinking ideas.	

You will also need to keep in mind the eight steps of the Engineering Design Process.

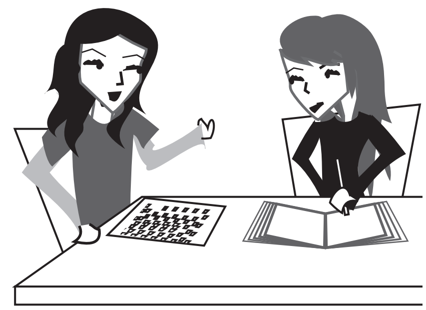


Initial ______________ Date ___________

TASK 2.1 Define the Problem

- Explain problems associated with urban sprawl.
- Analyze building space.

Urban sprawl is affecting the health and happiness of people around the world. City planners and government officials are trying to reverse the problems of urban sprawl by thoughtfully planning the locations and designs of new buildings. Conduct your own research on the problem of urban sprawl, and list some possible solutions to the problem in the space below. You may want to use the library or web sites for information.



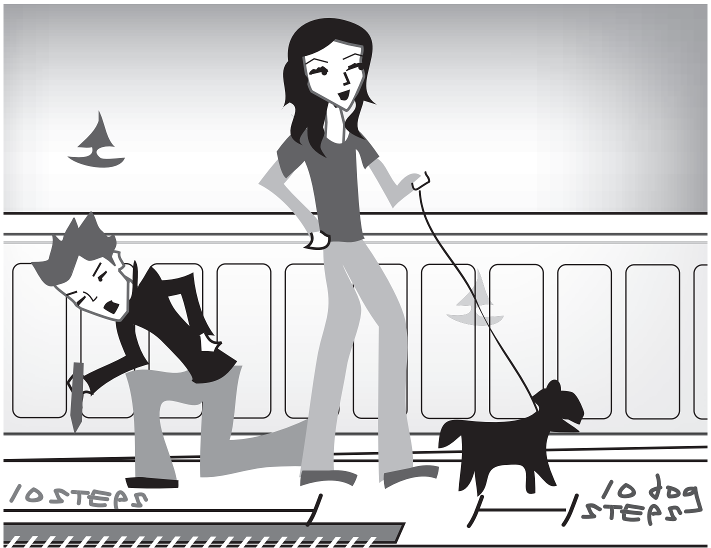
Engineers discussing solutions to urban sprawl.

Urban Sprawl

Urban sprawl describes the rapid expansion of a city toward surrounding areas, replacing farmland and natural habitats with houses, streets, and commercial or industrial buildings. In the space below, give an example of urban sprawl in your area or another area that you know about and describe some of the problems it may be causing.

New urbanists make optimum use of space. In order to do this, they must understand people's needs. The amount of space allocated for a new building is dependent on how it will be used. A fire station uses a different amount of space than a police station. Your home uses a different amount of space than the White House. In the next activity, you will research space usage by measuring and calculating square footage of floor area.

Researching Space: Calculate the Area



A quick and easy way to estimate distances involves counting your steps. To determine the length of one step, walk ten steps and use a yardstick to measure the distance you covered. Do this three times, recording the distance covered in the table below. Then divide each distance by ten, and write in the average step length for each trial in the right-hand column.

Calculate Your Space

	Distance of 10 steps (ft.)	Average length of one step
Trial 1		
Trial 2		
Trial 3		
Average of trials		

$$\text{Average length of one step} = \frac{\text{Total length (Sum of distance)}}{\text{Number of steps}}$$

$$\text{Average of trials} = \frac{\text{Sum of trials}}{\text{Number of trials}}$$

Estimate the area of a room by counting steps as you walk the length of the room and the width of the room. Convert the measurements from steps to feet. Lastly, multiply the length in feet by the width in feet to get the area in square feet.

Example:
A room is 8 steps wide and 12 steps long, and your step is 2 feet long:

width *(w)* = 8 steps × 2 ft./step = 16 ft.
length *(l)* = 12 steps × 2 ft./step = 24 ft.

Now use the following formula to find the area of the room:
Area (in square feet) = length (in feet) × width (in feet)

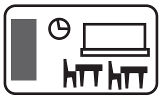
$$\boxed{A = l \times w}$$

So the area of the room is A = 16 ft. × 24 ft. = 384 $ft.^2$

Because area is two-dimensional, the unit of area is "feet squared," or $ft.^2$

1) Measure the length and width of your classroom and calculate the area. Show your work in the space below, and be sure to indicate units in feet (ft.) and square feet ($ft.^2$).

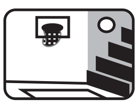
Your classroom:



2) Estimate the area of your bedroom and the school gym.

Your bedroom:

Your school gym:



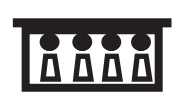
3) The "footprint" of a building is the entire ground area that it takes up. If you had to find the exact footprint of your school building, how would you do it?

Analyze Your Space

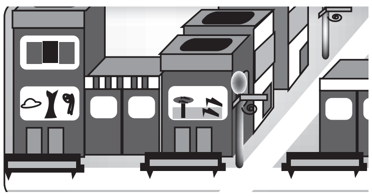
1) Could an apartment have the same square footage as a house? Why or why not?

2) Estimate the **usage density** (number of square feet ÷ number of people) of your bedroom and your classroom. How does the usage density compare? Does the type of use justify this difference?

3) Consider the usage density of different spaces in your school (classrooms, gym, corridors). How do they compare? Are they appropriately sized? If not, what do you think they should be? (Insert a sheet of notebook paper if you need more room to answer.)



Location, Location, Location



1) Which of these best describes the area where you live?

A. A large city (urban area)
B. A small city or town
C. A residential area on the outskirts of a city (suburban area)
D. A community where houses are widely scattered (rural area)
E. Other__________________________

2) Describe the “downtown” area closest to where you live.

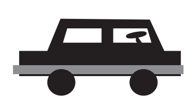
3) Are there commercial areas in your community, that are not in the center of town, where people can buy essentials such as groceries and medicines, or where they can mail a letter or get a haircut? If so, describe what these areas are like and how they differ from the “downtown” area.

4) Are there parks, green spaces, or recreation areas close to where you live? If so, what are they like? How do they make life different for people in your community?

5) How do people get to work or school in your community?

6) How has the location of homes and businesses in the area where you live affected the kinds of transportation available to people?

7) If you could change the way your community is arranged, how would you do it, and why?

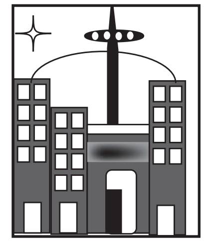


Read Chapter 10, “Redesigning America,” in the textbook *Engineering the Future,* in which Peter Park describes how new urbanism intends to combat urban sprawl and promote sustainable development. Use notebook paper to answer the questions at the end of the chapter. Sign, date, and number each page. Insert the pages at this point in your *Engineer’s Notebook.*

Initial ______________ Date ___________

Define the Problem

The engineering design process often begins with a problem that is only partly defined. In this case, the problem is to design a multi-use building that will help solve some of the problems of urban sprawl. In order to better define the problem you'll need to identify criteria (for a successful solution) and constraints (that limit what can be done).



Criteria

Below is one criterion that could be used to judge a successful design of a multi-use building. Suggest at least three other criteria that could be used to judge a successful solution.

1) The building will include apartments for several individuals, couples, and families, as well as at least one business or industry.

2)

3)

4)

Constraints

Below is one constraint that may limit the kind of building you could design. List at least three additional constraints that could be used to judge a successful solution.

1) The building will use a minimum amount of fuel for heating and cooling.

2)

3)

4)

Researching Space: Reducing Urban Sprawl

In the space below, write your initial thoughts about a multi-use building that would meet the criteria and constraints of the problem.

Sketch the ground floor of the building and label rooms to illustrate the different ways that it would be used by its occupants.

At the bottom of the page, explain why you think such a building would meet the criteria for a structure that would reduce urban sprawl.

TASK 2.2 Identify the Loads the Building Must Support

- Distinguish live loads, dead loads, and total loads.
- Figure out how strong your building will have to be.

The earliest set of known laws is the Hammurabi Code, written nearly 5,000 years ago. One of these laws is that if an architect designs a building that collapses and accidentally kills the owner, then the architect is to be put to death. Today architects depend on engineers to figure out how much weight a building must support, and what structures and materials are needed to support the load, plus a large safety factor. Although we no longer execute engineers for poor designs, learning to be a good engineer is still a life-or-death matter, and the first lesson to learn is how to calculate loads.

Will the ETF engineers be able to balance the loads?

Understanding Loads

Before you design an entire building, start with something simple: a deck. A deck is simply a floor designed to support people and objects. From an engineer's point of view, it doesn't matter if the deck is used as a front porch on a house or a stage for a rock band—you still have to calculate the loads that it has to support.

Types of Loads

Dead Load:
The weight of the structure itself.

Live Load:
All other forces on the object, including the weight of people, objects, and snow that the structure must support, as well as any additional forces such as wind, water, or earthquakes.

Total Load:
The sum of all live and dead loads. A structure must be designed so that it holds up the total load, plus a large margin of safety.

What's holding you up?
Look at the structure of your school. What is the overall shape? How many floors does it have? Is there a basement? How are the floors supported? Imagine you could look straight through the floorboards or tiles in your classroom. What do you think is underneath? What's holding up the floor you are standing on right now? In the space here, draw a sketch showing what you think is under the floor, holding it up.

Name ______________________________

DESIGN CHALLENGE

Following the steps on these three pages to design a deck, use the engineering design process. Sketch some ideas and build a model to test how the structural components you designed will support the dead and live loads.

Define the Problem

Imagine you have been asked to design a backyard deck to meet the following criteria and constraints:

Criteria

1) The deck area should be 8 ft. × 11 ft. and it should be 3 ft. high.

2) It should support at least 8 adults, 8 chairs, a table, and a charcoal grill, with a safety factor of 2.

3) The design should be tested with a 1:12 scale model to see how well it will support a load.

Constraints

1) The deck should be as inexpensive as possible (The scale model should use a limited number of straws, cardboard strips, paper, and tape.)

Safety factor is the number of times greater than the maximum total load that a structure is designed to support. For example, if a structure is expected to hold a maximum total load of 1,000 pounds, a safety factor of 2 means it would be designed to hold 2,000 pounds.

Research the Problem

An important aspect of researching the problem is to find out how others have solved it so you can avoid "reinventing the wheel."

Decks, porches, and floors are all constructed in much the same way. Look closely at any that you can find around school or home. Notice the boards that make up the walking surface, the frame the surface is attached to, and the supports that hold up the frame and anchor it to the ground.

Search the library or the Internet for plans about how to build a backyard deck. Notice what is similar about all of these, and write down notes and sketches. Add another sheet of paper to your *Engineer's Notebook* with your notes about how to build a deck.

Initial ______________ Date ___________

Develop Possible Solutions

Make three of four rough sketches showing different ways that you could build a deck with the dimensions 8 ft. long × 11 ft. wide × 3 ft. high. Do these on sheets of graph paper or notebook paper, and insert them here in your *Engineer's Notebook.* Give each design a different name or letter.

Choose the Best Solution

Create a Pugh chart, as in Project 1, to compare the different designs. Here's a chart prepared by one group of engineers. In their opinion, strength of support was more important than cost.

	Value	Design A	Design B	Design C
Strong Support	0–5	5	3	4
Low Material Cost	0–4	3	3	2
Total Points		8	6	6

Create a Prototype

After you've selected your design, build your model deck with a scale of 1:12.

Test and Evaluate

Place books or other weights on your deck one at a time, until it begins to fail. Note where the weak points are, and think about how to change the design to strengthen the weak points.

1) How much weight did the model hold?

2) Did you have trouble with the deck sagging in the middle? What change can you make to strengthen it?

3) Did you consider changing the location or orientation (change the strips from horizontal to vertical) of any of the structural members? If so, how did it affect the strength of the deck?

4) Make notes here and on your drawing to show how you would strengthen the deck.

5) Will this design solve the problem? If not, what design will you try next?

Communicate the Solution

On a separate piece of paper, make a scaled orthographic drawing of your final deck design. Look at the vocabulary below and identify the different components in your model. You may need to draw several views. List the advantages of your design and briefly summarize how well it performed when it was tested.

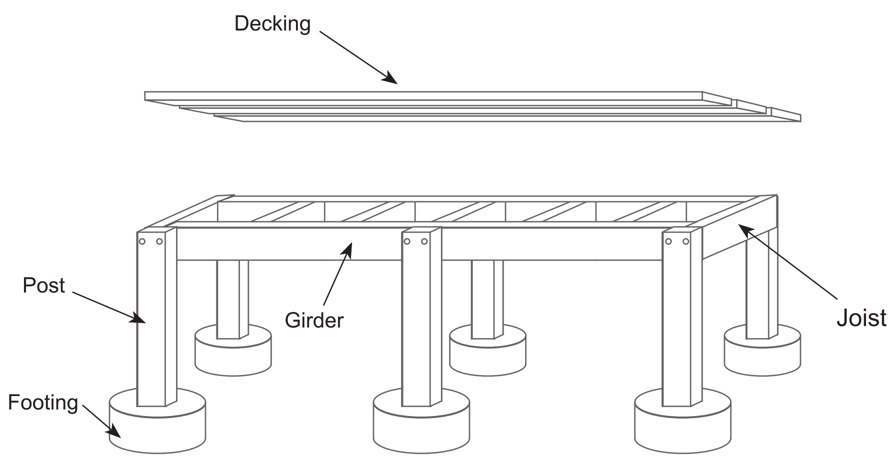
Joist: small supporting beam for the decking

Decking: panels that make up the flooring of the deck

Girder: large supporting beam for joists that transfers load to the posts

Posts: columns under the girders that hold up the deck and transfer load to the footings

Footings: cement piles in the ground

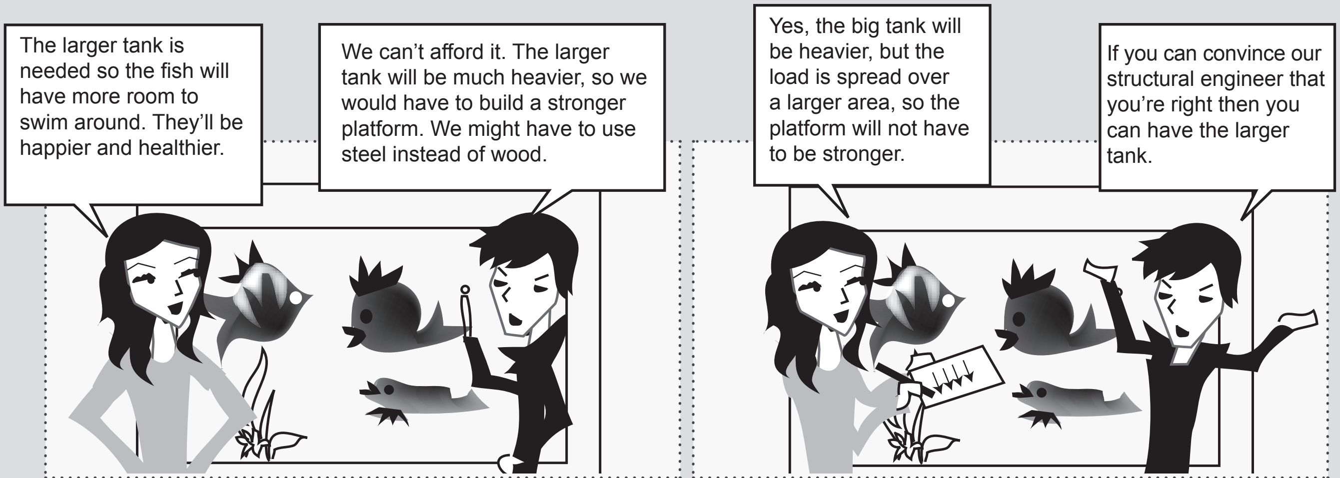


Redesign

It is very often the case that the "final" design needs to be improved, either because problems crop up, or because the client wants something a little different. That is why the last step in the engineering design process is "Redesign." As part of this task, write a paragraph or make a sketch showing how you would redesign the deck to hold an object weighing 1,000 pounds in the center of the deck, but with minimal additional cost. Insert it in your notebook after the drawings.

DESIGN CHALLENGE

City Aquarium has just acquired a family of rare fish. The new fish will be put into one of the spare tanks in the store room, but a platform must be built to support the tank. The director wants to use a tank with the dimensions 6 ft. × 6 ft. × 5 ft., while the curator wants to use a larger tank with the dimensions 8 ft. × 8 ft. × 5 ft. deep. They agree that the platform should have a safety factor of 3, but they disagree about the cost of building a platform. Here is their conversation.



Imagine that you are the structural engineer. Follow these steps to solve the problem and give advice to the director and curator:

Define the Problem

1) State the problem you have been asked to solve, and list any criteria and constraints.

The problem:

Criteria:

Constraints:

Research the Problem

2) You have determined that the platform must be the same size as the bottom of the tank. You have also found the following information:

- Each tank is filled until the water level is one foot from the top.
  The large tank weighs 400 pounds when empty. The small tank weighs 300 pounds when empty.
- 1 cubic foot holds 7.5 gallons of water.
  1 gallon of water weighs 8.34 pounds.
  (How much does 1 cubic foot of water weigh?___________lbs.)
- Volume = length × width × height
- The fish weigh 15 pounds.

Initial ______________ Date ___________

Make Calculations

3) Answer the following questions for each tank. Show your work below.

	Large tank 8 ft. × 8 ft. × 5 ft. deep	Small tank 6 ft. × 6 ft. × 5 ft. deep
Weight of tank (pounds)		
Weight of fish (pounds)		
Weight of water (pounds) (tank filled up to 4 feet)		
Total live load (pounds) (tank, fish, and water)		
Area of platform (ft.^{2})		
What is the minimum pounds per square foot (psf) that the platform must hold?		
With a safety factor of 3, how many psf must the platform be built to hold?		

What's Your Advice?

4) What advice would you give the director and curator? Will the platform have to be stronger to support the big tank? How much weight per square foot would the platform need to support in each case? (Don't forget to take into account the safety factor of 3.) Were you surprised by the result?

Building Codes

5) As soon as a decision has been made to build a deck or platform, it is necessary to design it so that it meets all requirements of the local building code. Research the allowable load for decks, platforms, or floors in your city or town. (If you can't find the information on the Internet, you can contact your City Clerk or Public Works Office.) Summarize what you find below.

Permits

6) After the deck or platform is designed so that it meets building codes, a building permit must be filled out and approved by city inspectors before work can begin. An example of a building permit is on the next page. If you were building a deck for your house, what information about the project would you need to fill in? (Answer below.)

Address	**Building Permit Application** **City of**	**Application No.** **Parcel No.**
Building Type	Single Family Two Family Detached Garage Deck Accessory Structure 3&4 Family Five or more Family Other______________________	
Building Site Address:		Suite No.
Owner's Name:	Mailing Address	Tel. FAX#
Tenant's Name:	Mailing Address	Tel. FAX#
Contractor's Name:	Lic/Cert# Mailing Address	Tel. FAX#
PROJECT DESCRIPTION		
PROJECT LOCATION	Lot area Sq. ft.	________1/4, ________1/4, of Section .T N, R E(or)W
Zoning District(s)	Subdivision Name	Lot No. Block No.
Sanitary Permit No.	Zoning Permit No.	**Set Backs** Front ft Rear ft Left ft Right ft

1. PROJECT	**2. STORIES**	**3. FOUNDATION**	**4. SEWER**	**5. WATER**
New Repair Alteration Raze Addition Move Other	1-Story 2-Story Other Plus Basement	Concrete Masonry Treated Wood Other	Municipal Private System	Municipal Utility Private On-Site Well

6. AREA INVOLVED			**13. HEAT LOSS**
Unfinished Basement __________Sq Ft	Finished Basement __________Sq Ft	Living Area 3rd Floor __________Sq Ft	__________BTU-HR Total Calculated
1st Floor Living Area __________Sq Ft	2nd Floor Living Area __________Sq Ft	Detached Garage __________Sq Ft	Envelope and Infiltration Losses ("Maximum Allowable Heating Equipment Output" on Energy Worksheet: "Total Building Heating Load" on Wischeck report)
Attached Garage Area __________Sq Ft	Open Porch Area __________Sq Ft	Other Area __________Sq Ft	**14. EST. BUILDING COST**
Deck Area __________Sq Ft	Enclosed Porch Area __________Sq Ft	**TOTAL Square Feet**	$

I agree to comply with all applicable codes, statutes, and ordinances and with the conditions of this permit, understand that the issuance of the permit creates no legal liability, express or implied on the state or municipality: and certify that all the above information is accurate. Expressly grant the building inspector, or the inspector's authorized agent permission to enter the premises for which this permit is sought at all reasonable hours and for any proper purpose to inspect the work which is being done.

APPLICANT'S SIGNATURE______________________________ **DATE SIGNED**______________

APPROVAL CONDITIONS This permit is issued pursuant to the following conditions. Failure to comply may result in suspension or revocation of the permit or other penalty. **See attached for conditions of approval.**

BONDS ISSUED	Occupancy Bond Erosion Bond Other # of Dwelling Units ___________	Municipality Number of Dwelling Location

PERMIT FEES:		**WIS PERMIT SEAL #**	**PERMIT ISSUED BY:**
Permit $__________ Permit Seal $__________ Occupancy Bond $__________ Erosion Bond $__________ Other $__________			Name____________________ Date____________________ Cert No.____________________

Benchmark

1) If you are designing a doctor's office, you will need to add up the weight of all live loads in order to calculate how strong the building foundation must be. Circle all of the live loads.

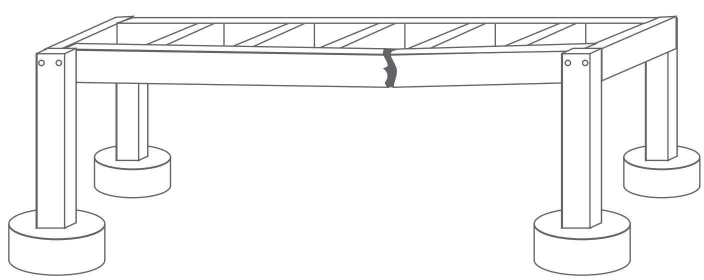
Roof	Medical equipment	Flooring	Chairs
Desk	Telephone	Stethoscope	Patients
Pictures	Coat rack	Walls	Windows

2) What is a "safety factor"? Why is it important?

3) Why is it important to conduct research before coming up with solutions to a problem?

4) What is the difference between a "building code" and a "building permit"?

5) A scale model of this deck frame failed a strength test. Show at least two things you could do to strengthen it by sketching in parts that you would add or change.



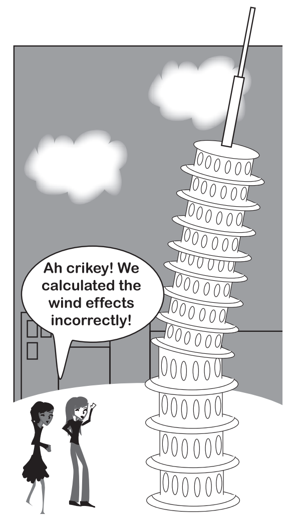
Read Chapter 11, "Bridging the Future," in the textbook *Engineering the Future,* in which Kirk Elwell talks about designing Boston's Zakim bridge and how it was designed to hold live and dead loads. Use notebook paper to answer the questions at the end of the chapter. Sign, date, and number each page. Insert the pages at this point in your *Engineer's Notebook.*

Initial ____________ Date __________

TASK 2.3 Use Failure Analysis to Design a Safer Building

- Build a prototype tower and test it.
- Fail early and often to succeed sooner!

Building and testing prototypes is an important part of the engineering design process and is used by nearly all engineers. It has a special meaning for structural engineers whose worst nightmare is a completed building or bridge that collapses, injuring or killing people. To prevent that from happening, structural engineers build and test scale models. Failure analysis involves building a scale model and testing it with various loads to see how strong it is and where it breaks, or "fails." The goal of this process is to identify weak aspects of a design and possible failure sites, so that the design can be strengthened before construction starts.



DESIGN CHALLENGE

This is a TEAM ACTIVITY in which you and your teammates will go through the engineering design process to design and build a tower, and analyze how it failed.

Problem Statement: Design and build a prototype of the tallest tower that supports the largest load, with the least cost. Test the prototype and identify the weak points and types of failure. Write a report, describing what you accomplished and what you learned.

Criteria:
A successful tower design will

- be at least two feet high.
- support a live load of at least 2 pounds (or other standard load set by your teacher).
- be freestanding (not attached to any surface).

Constraints:
The materials used for construction of the prototype are limited to

- notebook paper.
- straws.
- masking tape.
- paperclips.

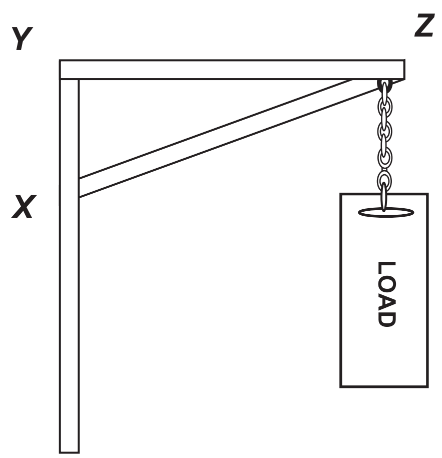
Tip: Before you begin, look at the rubric on the last page of this task to see how your work on this challenge will be evaluated.

Research the Problem

Before designing your tower, think about the forces that will act on it. When a load is applied, the tower will act as a system to support the load. But different components of the system will be subject to different forces. Following are two types of forces:

Tension: A stretching force that happens when you pull the ends of an object apart.

Compression: A squeezing force that happens when you push the ends of an object together.



Consider the system of beams shown.

The force acting on the system is divided among the various beams that react by pushing or pulling to keep the load from moving.

Some of the beams are in tension and some are in compression.

- To determine which beams are in tension or compression, pick a beam, imagine that you cut it, and predict what would happen to the two halves of the beam.
- For example, look at the beam at the top, *YZ*. If you were to cut it in half, would the two halves pull apart or push together?

  — If they would pull apart, the beam is in **tension.**
  — If they would push together, the team is in **compression.**

In the spaces below, write whether you think each beam is in tension or compression.

YZ ____________________

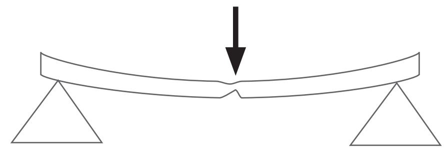
XY ____________________

XZ ____________________

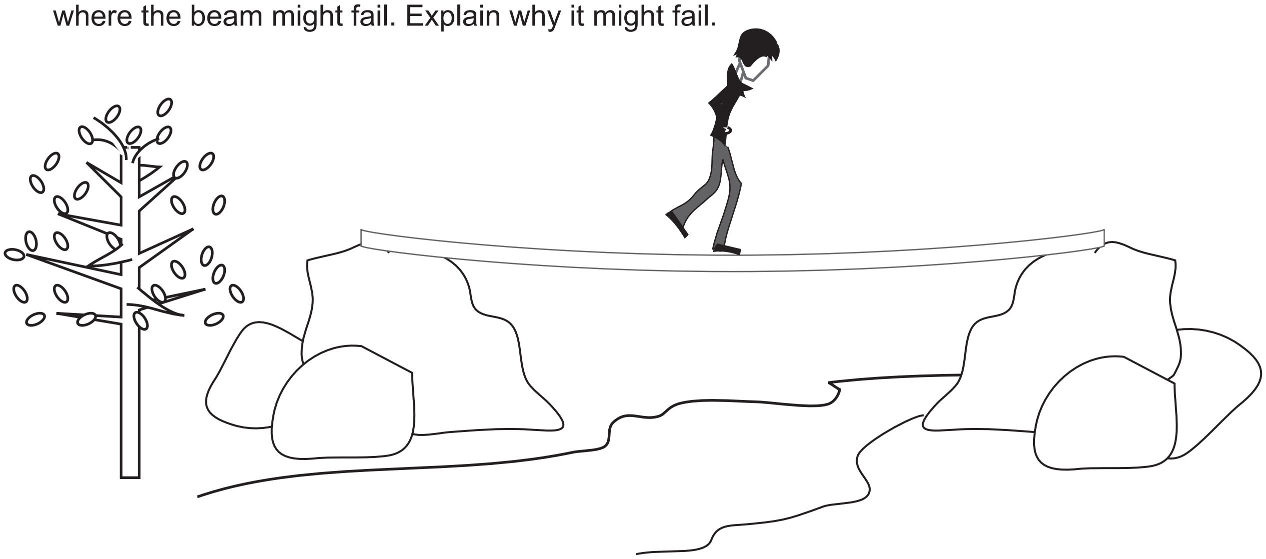
Initial ______________ Date __________

Bending

When a beam is suspended by both ends and a force is exerted in the middle, the top of the beam is compressed, while the bottom is pulled apart. This is called **bending.** If the tension along the bottom of the beam is too great, the beam will fail.



In the picture below, in which a person is crossing a stream on a simple beam bridge, place a mark to show where the beam might fail. Explain why it might fail.



Develop Possible Solutions

On the next page is a budget sheet for the materials that you can use to build your tower. You can see that they are quite expensive, so you will want to use as few materials as possible to build the tallest tower that will support the greatest live load. Sketch several different ideas on a sheet of notebook paper and insert your sketches here.

As you design, think about the following:

- Which materials are strongest for use in tension or compression?
- How can these materials be shaped so they will be stronger?
- How can the materials be fastened so the joints are strong?
- What design elements will make the tower tall and stable?
- What design elements will hold up heavy live loads?
- What design elements will make it an attractive structure?

Choose the Best Solution

- Which design will make the tallest tower?
- Which design will make the strongest tower?
- Which design will make the least expensive tower?
- Which design elements can be combined to meet all three criteria?
  Sketch the best solution in the space below.

Create a Prototype

"Purchase" the materials you will need. Record the number of each item so that you can calculate the cost. Build your tower.

- Sketch your finished tower on an additional page before you test it.
- On the sketch, list all of the materials that were used to build it.

	UNIT COST	NUMBER OF ITEMS	TOTAL COST OF ITEM
Notebook paper	$1,000		
Masking tape, per inch	$600		
Straws	$900		
Paper clips	$750		
		Total cost:	

Test and Evaluate

Does It Meet the Criteria?

1) Measure the height of your tower in feet and inches, and determine how much it cost to build.

Final height: ____________________ Cost of materials: ________________

2) Carefully place a two-pound (or other standard) weight on the top of your tower to test if it will support the required live load. Is the load (Circle A., B., or C.):

A. Fully supported? B. Partly supported? C. Not supported (tower collapsed)?

3) Does your tower meet the criteria and constraints of the problem? Summarize your conclusion here:

4) On the sketch of your finished tower, make labels and notes to illustrate important features that give it height, stability, and strength.

Failure Analysis

It's usually not enough just to meet the criteria and constraints. Next you will analyze your design to see why it fails and how it can be improved.

1) Carefully add weight little by little until your tower just begins to fail. Record the maximum weight and identify which of the forces below caused failure.

2) Identify the weak points in your tower design and mark them on your sketch. Discuss what might be done to strengthen the weakest points. Insert the sketch at this point in your *Engineer's Notebook.*

Tension: Tension is a stretching force that happens when the ends of an object are pulled apart. Fracture lines result when a material begins to break due to tension.

Compression: Compression is a squeezing force that happens when the ends of an object are pushed together. Buckling is a failure that results when the compression forces exceed the compression limits of the material.

Bending: Bending is when one side of an object experiences tension and the other side experiences compression, as when a long object is supported at its ends and a load placed in the middle. Permanent bends or curves in supporting beams result if the bending force is too great.

Torsion: Torsion is a twisting force that happens when one end of an object is rotated in one direction while the other end is held still or rotated in the opposite direction. Permanently twisted members result from torsion failures.

Shear: Shear forces occur when part of an object is pushed one way and another part of the object is pushed in the opposite direction. Powerful shearing forces can tear, break, bend, or otherwise deform structural members.

Name ______________________________

Safety Analysis

Buildings, bridges, and other structures are always designed to support more than the maximum weight expected. Find the safety factor (S_F) for your tower by dividing the weight that your structure supported before failure by the maximum expected load. Show your calculation below.

$$S_F = \frac{\text{Maximum load the structure will support (measured in test)}}{\text{Maximum expected load (2 lb.)}}$$

Note: If your structure did not hold the standard weight, then the safety factor is 0.

Benefit/Cost Analysis

In order to compare different designs, engineers sometimes calculate the "Benefit/Cost Ratio."

In this problem, the benefit of your design can be calculated as the height of the tower times the load it can support, while the cost is just the cost of materials.

Calculate the Benefit/Cost Ratio of your tower in the space below.

$$\text{Benefit/Cost Ratio} = \frac{\text{Height (ft.)} \times \text{maximum load (lb.)}}{\text{Total cost of materials (\$)}}$$

Initial ______________ Date ___________

Communicate

Write a report of your tower project. Even though this is a team effort, each person should write his or her own report.

1) Sketch your tower before it fell, labeling the various components of the tower and why they are there.

2) With a colored pen or pencil, identify each of the weak points in the design, writing in the type of force that caused the failure.

3) In the written portion of your tower project report, make sure to include the following:

- The overall plan for your tower (why it's a good design).
- Did it meet the criteria and constraints of the problem?
- How safe is this design?
- What are the weakest points under extreme live loads?
- What is the benefit/cost ratio of your design?

Redesign

4) Conclude your written report by explaining how you might redesign the tower so it is taller, stronger, or less expensive.

Evaluate Your Work

5) On the next page is a rubric for judging how well you did on your Tower Design Challenge. Apply the rubric to your report and determine how you think it should rate. Explain your self-rating below.

I believe my report should receive _____ stars because

Read Chapter 12, "Tower in the Sky," in the textbook *Engineering the Future,* in which Bill Baker describes how he designed a multi-use skyscraper to be the tallest building in the world and to withstand live loads of people and wind. Use notebook paper to answer the questions at the end of the chapter. Sign, date, and number each page. Insert the pages at this point in your *Engineer's Notebook.*

Rubric for Design and Build a Tower

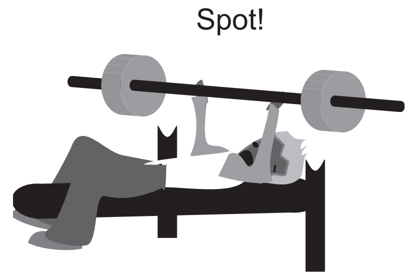
	✧✧✧✧	✧✧✧	✧✧	✧
Define the Problem	Problem is successfully defined in terms of all criteria and constraints.	Problem is defined but is missing one or two criteria and constraints.	Problem is defined by only one or two criteria and constraints.	Problem is oversimplified. No criteria or constraints mentioned.
Research the Problem	Several sources of information. Research very informative and applicable.	Few sources included. Research somewhat helpful.	Little evidence of research.	No research.
Develop Possible Solutions	Three or more design alternatives clearly sketched.	Two design alternatives sketched.	One design sketched.	No sketches.
Prototype Testing	Prototype testing results and redesign well documented. Material sheet is neatly completed.	Some prototype testing results and redesign documented. Material sheet is included.	Very few results documented. Material sheet is included.	Minimal prototype testing completed. No material sheet is included.
Failure Analysis	Failure is located specifically and reasons are thoughtful and logical. Construction of structure taken into account.	Failure is commented upon but not located. Reasons are oversimplified.	Failure is addressed briefly.	No failure analysis.
Communication	Report well written and illustrated with research, sketches, material choices, costs, test results, failure analysis, and redesign ideas.	Report is clear and includes nearly all required sections.	Report includes most required sections.	Report missing or incomplete.
Teamwork	I helped my teammates be more effective and contributed in major ways to the team.	I worked well with my teammates and did all I was supposed to do.	I did everything I was supposed to do.	I contributed a little to my team.

Initial ______________ Date ___________

TASK 2.4 Test Construction Materials for Strength

- Test various types of materials for different aspects of strength.
- Use failure analysis in designing.

When you design your multi-use building, you will need to specify which materials should be used for various parts of the structure. You will want to select materials for the various components that are best able to withstand the forces that they are likely to bear when the building is subject to changing live loads from people, equipment, wind, and snow.



The load is just right for the engineer's strength!

Basics of Failure Analysis

In Tasks 2.4 and 2.5 you will conduct tests on various materials to see how well they hold up under tension, compression, torsion, bending, and shearing forces. Although you will be testing common materials, such as paper and straws, materials engineers use the same approach to test glass, steel, concrete, and other heavy construction materials.

The **failure analysis** that you will be doing in this task can be applied to entire buildings and also to individual structural components. The purpose of failure analysis is to identify potential problems before they happen, so as to save lives.

Failure analysis can be divided into four main areas:

- **Failure modes:** the way the object failed—for example, suddenly or gradually
- **Failure site:** where in the object failure occurred
- **Failure mechanism:** what physically happened in the failure
- **Root cause:** the aspect of design, defect, or load that lead to the failure

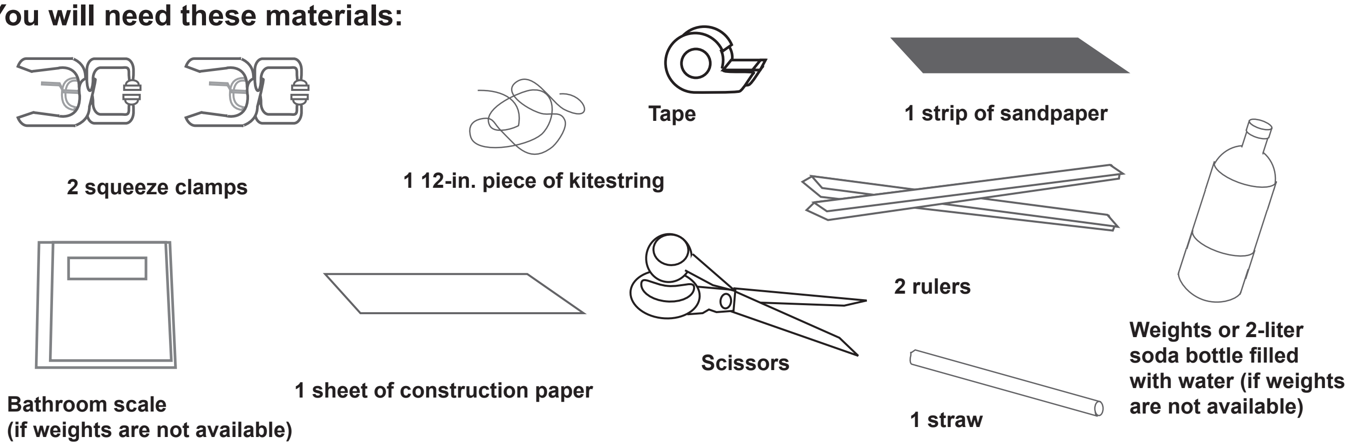
Tensile Strength

The **tensile strength** of a material is a measure of how hard it can be pulled apart before it breaks.

For example, in a suspension bridge, the entire roadway—including the steel structure that supports the road and the live load of people and cars—is suspended from thin cables that hang from a larger cable strung over two or more towers. There is a lot of tension in all of the cables. If any of them were to snap, the roadway would sag, cars might fall off, and additional tensile stress would be put on all of the other cables, possibly leading to a total collapse. The only way to be sure this will not happen is to test the cable material before it is used to build the bridge.

Build a Materials Testing Device

You will need these materials:



Build a device to measure the tensile strength of various materials, as follows:

1) For the support system, tape or tie the rulers together to create a strong 12-in. long beam. Support the beam at the ends with two desks (see picture to the right).

2) For the first sample, cut a 3"-long × 3/8"-wide sample of construction paper. Clamp the paper at both ends, taking care not to fold or rip it.

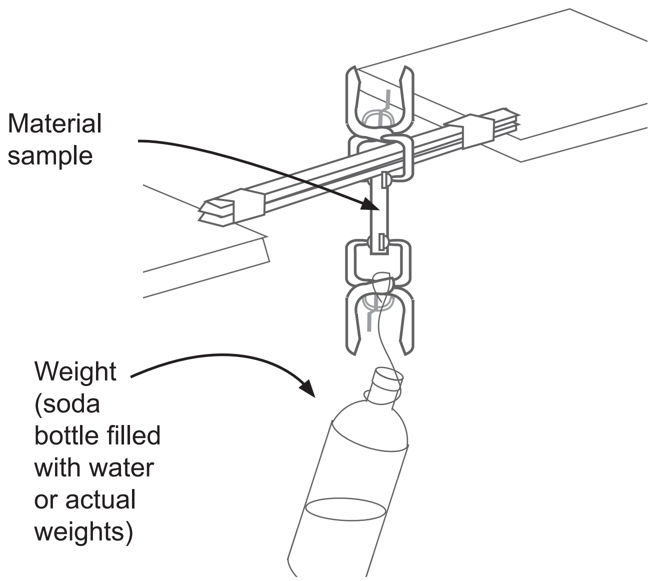
3) Now hang the clamp system onto the support system by pushing the ruler through the top clamp. Hang it as close to the center as you can.

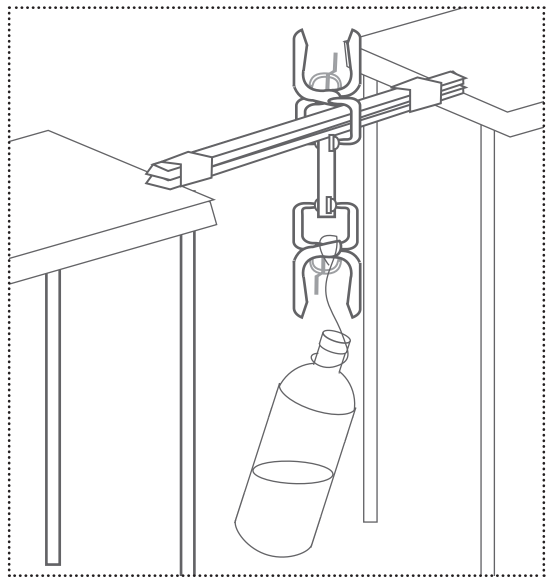
4) Attach a loop of string or a weight hanger to the lower clamp.

Tensile Strength of Paper

Use the device as follows:

- The weight pulls down on the lower clamp, which puts tensile stress on the sample.
- Add more and more weight until the material breaks.
- The maximum amount of weight that the sample can support before it breaks is the tensile strength of the material.





1) Predict how much weight the paper will hold. Write your answer here. _______________

2) Start by hanging a half-pound weight and add weight little by little until the material fails. What happens? Draw a quick sketch of what happens to the paper at the point of failure.

3) What is the maximum load the construction paper supported before failing? Don't forget to indicate units.

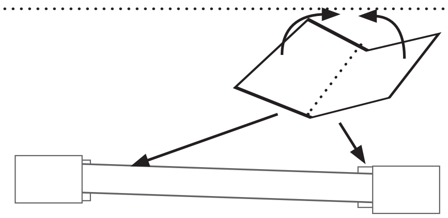
4) If time permits, repeat this experiment with notebook or copy paper. Predict the maximum load, run the test, and compare the results.

Name ______________________________

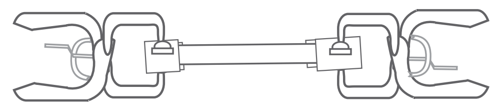
Tensile Strength of a Straw

1) Use scissors to slice open and cut a straw so it is approximately 3/8" wide and 3" long.

2) To hold the straw in place, cut out two 1 × 1-inch pieces of sand paper. Fold them in half (rough sand side facing out), and fold again the long way around the ends of the straw so that the rough side will be in contact with both the straw and the clamp.



3) Attach the clamps to the sand paper ends.



4) Now load the straw using the same setup as the paper test. What happens to the straw? Describe in detail and make a sketch of the failure point.

Sample	Maximum Weight	Sketch of Failure Site
Construction paper 		
Straw 		

5) How do the tensile strength and failure mode of these two materials differ?

Initial ______________ Date __________

Compressive and Bending Strength

Compressive strength of a material is a measure of how hard it can be pushed together before it is crushed.

Bending strength is a measure of how hard a material can be pushed in the center, while the two ends are held stationary, before it breaks.

You can get a feeling for the compressive and bending strength of some materials with some very simple tests. You will need two of each item you are testing—one to test compression strength and the other to test bending strength. Prepare the following samples for testing:

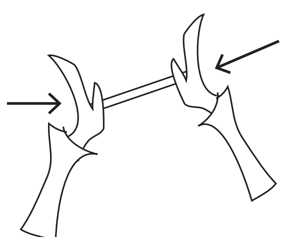
Two half-sheets of paper rolled into a cylinder the long way and taped in place.

Two half-sheets of paper rolled into a cylinder the wide way and taped in place.

Two empty cardboard toilet paper rolls or paper towel rolls.

Two plastic straws.

Compression Test

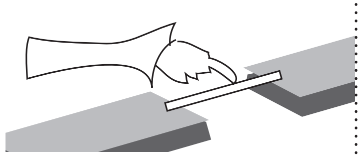


First, predict which you think will have the greatest compressive strength.

Then hold one of the samples lengthwise between your palms and slowly push your palms together. Observe how it fails.

Do the same for the other three samples. Describe how they fail in the table on the next page.

Bending Test



Predict which of the four samples will have the greatest bending strength. Then place one of the samples on its side so it is supported on each end by two books or desks, about 8 in. apart.

Use one finger to press downward in the center of the sample until it just begins to bend. Release it and see if it bounces back to its previous shape.

Again, use one finger and press downward in the center of the sample until it bends so much that it will not bounce back to its previous shape. Describe your findings in the table on the following page. Test all of the samples the same way.

 Name ____________________

Summarize Your Test Results

In this task you tested the effects of three types of forces on various materials: tension, compression, and bending. Now summarize your findings in the following table. Use measurements with units when applicable to show how each material stood up under that force. (Tests you did not perform are shown in gray.)

	Tension	Compression	Bending
Strip of paper		(gray)	(gray)
Wide paper roll	(gray)		
Long paper roll	(gray)		
Cardboard roll	(gray)		
Straw			

1) Even though you did not do all the tests with all of the materials, you can now compare and predict how some of these materials perform under different kinds of forces. Which material performed the best for each type of loading?

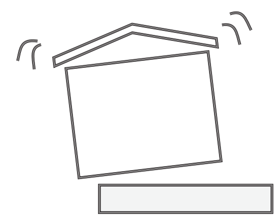
2) Suppose a structural engineer finds that a roof weighs 10,000 pounds. Is it sufficient to use a roof beam that has a bending strength of 10,000 pounds? If not, about how much weight should the beam be capable of supporting? Explain your answer.

Initial ____________ Date __________

Testing for Shear Strength and Torsional Strength

The **shear strength** of a material is a measure of how hard one part can be pushed or pulled one way while another part is pushed or pulled the opposite way, without breaking.

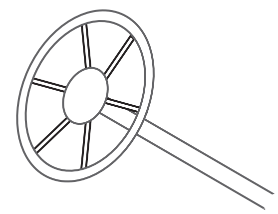
The shear strength of materials is important in certain situations. For example, in earthquakes shearing forces can knock buildings off their foundations, which can cause them to collapse, trapping people inside. This happens when the ground moves back and forth sideways, while the building tends to remain still due to inertia. Residents in earthquake zones are urged to bolt their houses to their foundations, so that the entire building moves with the foundation. The bolts need to have very high shear strength, or they will break during a large earthquake.



Devise a method of testing bolts for shear strength. Draw a diagram of your test device below and explain how it works.

The **torsional strength** of a material is a measure of how much twisting force it can withstand without breaking.

Torsional strength is important whenever a material is subject to twisting forces. For example, the shaft of the steering wheel in a car is twisted millions of times during its lifetime. The shaft of a boat propeller or a helicopter blade is subject to even greater torsional forces. The material used in these shafts must have great torsional strength or it could result in catastrophic failure.



Devise a method of testing propeller shafts for torsional strength. Draw a diagram of your test device below.

Read Chapter 13, "Home Sweet Home," in the textbook *Engineering the Future,* in which Prity Rungta describes how she manages the construction. Use notebook paper to answer the questions at the end of the chapter. Sign, date, and number each page. Insert the pages at this point in your *Engineer's Notebook.*

TASK 2.5 Describe Mechanical Properties of Materials

- Explore different mechanical properties of materials.
- Discover the importance of stress and strain.

In the previous task you tested materials to their breaking point. But in designing your multifunction building, you will need to be aware of other mechanical properties besides strength, because different parts of buildings are subject to different kinds of forces. For example, below are some terms used to describe types of materials and how those materials act under different forces.

Types of Materials

Elastic materials change their shape when under a load, but return to their original shape when the load is removed.

Plastic materials also change their shape when under a load, but they remain permanently deformed when the load is removed.

Brittle materials break or crumble rather than deform under a load.

Malleable materials can easily be shaped by hammering or rolling, and they keep their new shape. Some materials can be made more malleable by heating.

1) Given your personal experience with materials, do your best to fill in the blanks.

A. Copper is more ___________________ than steel.

B. Steel is more ____________________ than concrete.

C. Concrete is more _________________ than steel.

D. Rubber is more __________________ than plastic.

E. Melted plastic is more _________________ than hard plastic.

2) Use different materials than those above to fill in these blanks.

A. _________________ is more elastic than _________________.

B. _________________ is more plastic than _________________.

C. _________________ is more brittle than __________________.

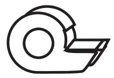
D. _________________ is more malleable than ________________.

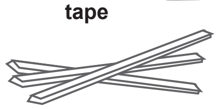
Measuring Elasticity

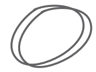
It may surprise you that steel is somewhat elastic. That is, when a steel cable is under tension, it will stretch a little. How much a material stretches under different loads is important to engineers. Because it requires expensive equipment to measure the elasticity of steel, in this task you'll measure how much an elastic band stretches under different loads.

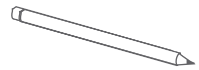
You will need these materials:

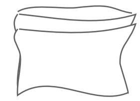

1 12-in. piece of kitestring

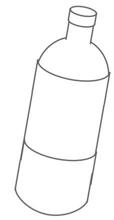

tape


3 rulers

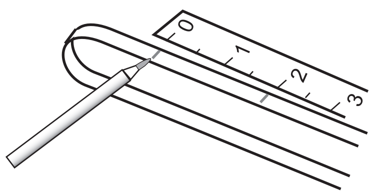

1 large elastic band


fine point felt marker

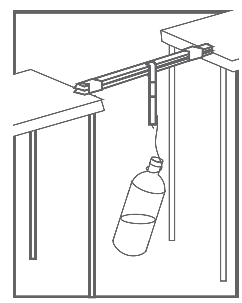

1 thin plastic bag from fruit or vegetables


weights or 2-liter soda bottle filled with water and bathroom scale

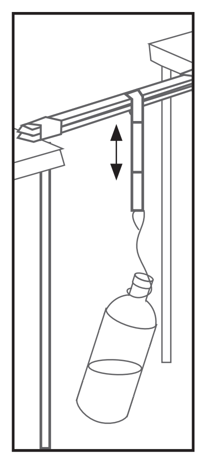
1) Mark two lines two inches apart on an elastic band.



2) Suspend the elastic band from two rulers taped together. Hang a small weight off the bottom.



3) With the weight hanging, measure and record the change in length between the two lines (elongation).



Elongation (ΔL) = new length (L_1) − original length (L_0)

$$\Delta L = L_1 - L_0$$

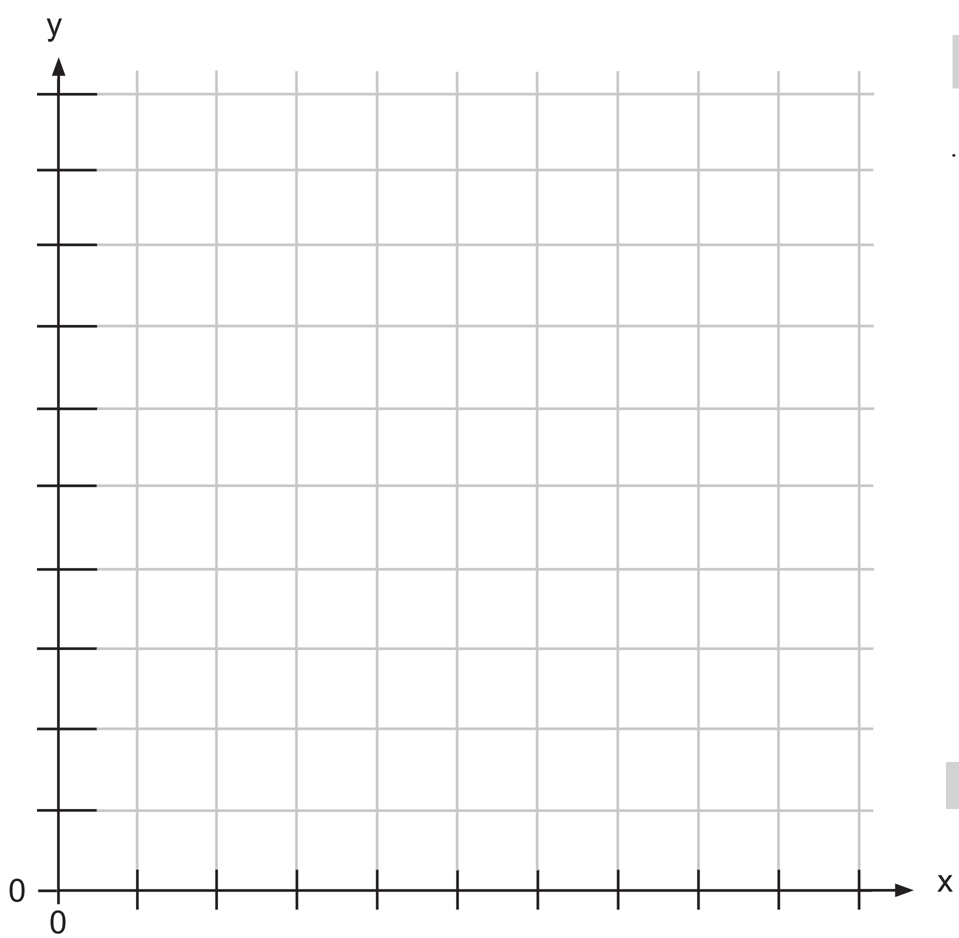
4) Unload the elastic band by holding up the weight. Does it go back to its original length and shape?

5) Add different amounts of weight and measure the elongation for each different weight. After each measurement, hold up the weight and measure to determine whether it returns to its original length. Record your observations on the next page.

Initial ____________ Date ____________

Weight	New length L_1	—	Original length L_0	=	Elongation ΔL	Return to original shape? Y/N
		—		=		
		—		=		
		—		=		
		—		=		
		—		=		
		—		=		
		—		=		
		—		=		
		—		=		
		—		=		
		—		=		

6) Plot each of the data points, with elongation on the *y*-axis and load (weight) on the *x*-axis



Good Graphing

1) Label *x*- and *y*-axis

2) Choose increments for axes that make sense. For example, if the *x* values range from 0 to 5 lb., and there are 10 tic marks, you could use increments of 1/2 lb.

3) Label the *y*-axis the same way.

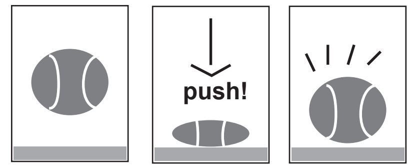
Be sure to label the axes and indicate the units.

4) Plot each point carefully.

Analyzing Elasticity

1) Look at your graph on the previous page. In the elastic region, a load will cause deformation but no damage is done to a material. The object will return to and maintain its original shape. Can you identify the region on the graph where the elastic band returned to its original shape? Label this area the “elastic region.”

2) At the elastic limit, the object will not return to its original shape. Can you identify the point where the elastic band no longer returned to its original shape? Label this point the “elastic limit.”



3) If possible, identify the part of the graph after the elastic limit and label this area the “plastic region.” Describe here how the material looked or behaved after it reached this limit.

4) Test plastic from a plastic bag used to carry fruits and vegetables. Cut a 1/2-in. slice the wide way so that the plastic makes a large loop. Use the same method used to test an elastic band to measure the elastic properties of the plastic bag. Answer these questions.

A. What is similar and different about the properties of the elastic band and plastic from the bag?

B. Which material is more elastic? How do you know?

C. Which material is more plastic? How do you know?

D. Think about how useful a bag would be if made from the material used to make elastic bands, and how useful an elastic band would be if made from the same material used to make plastic bags. Then make a general statement about what designers should be aware of when choosing a material for a particular purpose.

Stress and Strain

When choosing materials for a particular purpose, engineers consider the stress that will be put on the material, and the strain that will result. The definitions of these words are a little different from their use in everyday language.

Stress is the force *(F)* applied to a unit area *(A)* of an object. Stress is measured in force units, such as pounds (lb.), divided by area units, such as square inches (in.^{2}).

$$\text{Stress}\ (\sigma) = \frac{F}{A}$$

σ = Stress
F = Force
A = Area

Strain is the amount that a material deforms due to the applied stress. Strain is measured as a change in length (ΔL) divided by the original length of the object (L_0).

$$\textit{Strain}\ (\varepsilon) = \frac{\Delta L}{L_0}$$

ε = Strain
ΔL = Change in length of a material when stress is applied
L_0 = Original length of the material

Measuring how much materials strain when under tensile stress is very important for all structural designs, whether the purpose is to design a bridge, the body of an airplane, or a multi-use building.

1) On the chart of the elastic band that you created, choose a load before the elastic limit.

A. How much did the elastic band expand at that point? ΔL = ________

B. What was the strain at that point? $\frac{\Delta L}{L_0} =$ ________

2) Now choose a load after the elastic limit.

A. How much did the elastic band expand at that point? ΔL = ________

B. What was the strain at that point? $\frac{\Delta L}{L_0} =$ ________

3) What does this tell you about what will happen if you exceed the loading limit of a material?

4) Research engineers have created graphs like the one you made for many different types of materials. Why do you think engineers find these graphs useful?

Read Chapter 14, "From the Ground Up," in the textbook *Engineering the Future,* in which Cathy Bazan-Arias explains how important it is to take into account both the mechanical properties of the materials used and the ground on which a structure is built. Use notebook paper to answer the questions at the end of the chapter. Sign, date, and number each page. Insert the pages at this point in your *Engineer's Notebook.*

Benchmark

1) "Failure" means something different in engineering than in everyday life. Explain how engineers use failure to do their job better.

2) Give an example of situations in which you might observe the following forces:

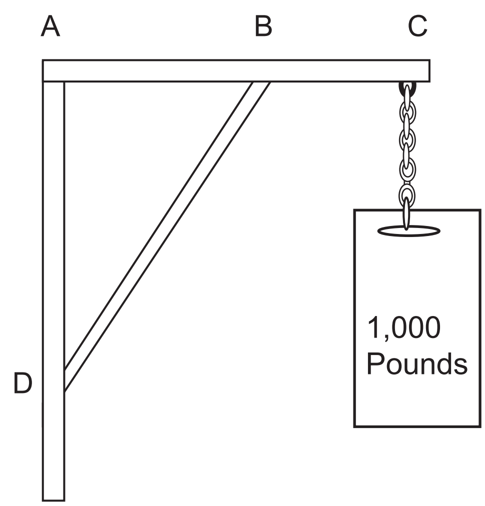
Tension:

Compression:

Torsion:

Shear:

3) Circle the point on this structure where there is the greatest stress, and therefore where a beam is more likely to break.



4) What kind of force is exerted

on beam AC?

on beam BD?

on beam AD?

5) Bridges are designed to have great compressional strength because they need to support very heavy loads. But in a storm with high winds the stress is likely to come from the side. What type of force is exerted on the supporting towers of a bridge during a storm?

6) Tensile stress tends to lengthen beams or other structural members. Compressional stress tends to shorten structural members. How do you think torsional stress might affect the shape of a member?

Initial ______________ Date ___________

TASK 2.6 Experiment with Concrete

- Experiment with material properties of concrete.

Without a firm foundation your house will collapse. Most foundations are made of concrete.

Aggregate is a dry mixture of sand and gravel in which the grains are different sizes.

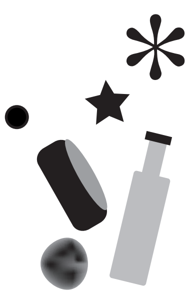
Cement is the “glue” that holds the aggregate together.

Concrete is a mixture of cement, water, and aggregate.

Sometimes dry cement and aggregate are mixed before they are bagged so that the only additional step is to add water and mix. The concrete can then be shaped for a while before it starts to harden.

A Word on Aggregates

The strength of concrete depends on the proportions of cement, water, and aggregate in the mixture as well as the composition of the aggregate.



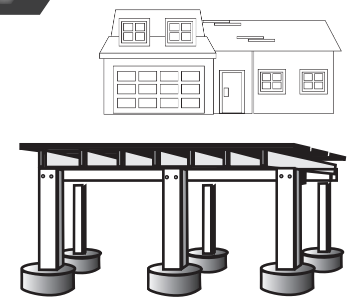
- **Aggregates** for concrete come in many different sizes, shapes, and materials.
- Traditional concrete is made with different grades (sizes) of sand and gravel.
- New research is being done to use alternative materials for aggregate such as recycled tires, glass, and demolition materials.

What impact do you think the choice of aggregate material has on the cost of the aggregate?
How does this affect the reusability of the concrete?

Name ______________________________

DESIGN CHALLENGE

The foundation of the house you design will need great compressive strength to support the total load of the structure. The challenge for your team will be to determine the best concrete recipe for the foundation so it will have as much compressive strength as possible.

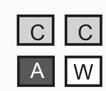


Define the Problem

Determine the best concrete recipe for the foundation so it will have as much compressive strength as possible.

Research the Problem

You will need to decide on the proportions of aggregate, cement, and water for your test samples. Use the library or Internet to learn more about the composition of concrete. Mixtures will vary.



Develop Possible Solutions

Consider the differences in aggregate that you could use. Which do you think will make the strongest concrete? Consider the different proportions of water, aggregate, and cement that you might use.

Choose the Best Solution

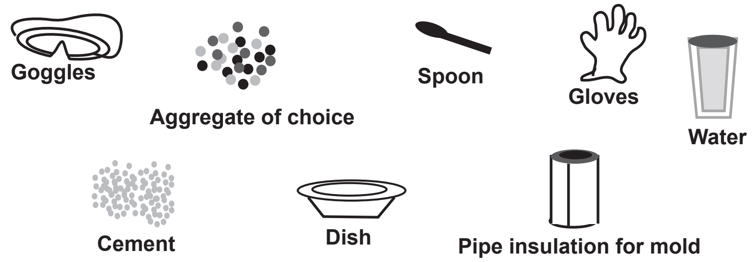
Choose one variable that you think will make the biggest difference in compressive strength (for example, proportions of water and cement, type of aggregate, or shape of column). Plan to make at least two samples that differ in only one way.

Create a Prototype

You will not be able to test the concrete with your hands as you did with the rolls of paper, so you will need a test apparatus called a **concrete crusher.** Only one concrete crusher will be needed for the whole class; teams will take turns using it. First, however, you will need to make the test samples. Follow the instructions on the next page.

Initial ______________ Date ___________

You will need these materials:



Concrete may irritate your skin. Gloves are strongly recommended when you are handling concrete.

Before You Begin

- Use the following table to record the amount and type of each material you use as well as the total setting time for your samples.
- Decide on a unit of measure. Spoonfuls? Cupfuls? Ounces?
- Cylinders should be no more than 1/2 in diameter across or they will be hard to crush.
- The height of the test cylinders should be at least twice as tall as the diameter. However, a cylinder that is too tall will tend to buckle.
- Make both samples the same height and diameter, and use the same setting time so that the only difference will be their composition.

Sample 1

Material	Amount

TOTAL SETTING TIME:

Sample 2

Material	Amount

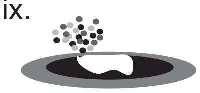
TOTAL SETTING TIME:

 Name ____________________

Mold the Column

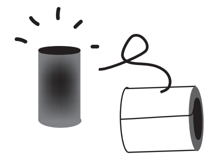
1) Combine the cement and water in a dish and mix until the mixture is smooth.

2) Add the aggregate and mix.



3) Pack the material into the mold. Make sure the mold is smooth on both ends by packing the column on a flat surface.

4) When the column is dry (usually after 24 hours), remove the mold.



Make Predictions

Sample 1 Prediction

Explain how you made this sample and why you think it will be especially strong or weak. Estimate how many pounds of compressive force it will withstand before it fails.

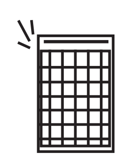
Draw a sketch showing how you think it will look just after it is tested. Show where you think the failure will occur and what it will look like.

Sample 2 Prediction

Explain how you made this sample and why you think it will be especially strong or weak. Estimate how many pounds of compressive force it will withstand before it fails.

Draw a sketch showing how you think it will look just after it is tested. Show where you think the failure will occur and what it will look like.

How will you judge the samples?
As a class, develop a chart that will help you distinguish the different properties of aggregate materials, their amounts, and how well they strengthen the concrete. Be sure to record at least the maximum load needed to break each column. At the end of testing, compare the results from all groups to determine the best recipe for creating the foundation. Insert your chart on a separate page. Be sure to sign and date it.



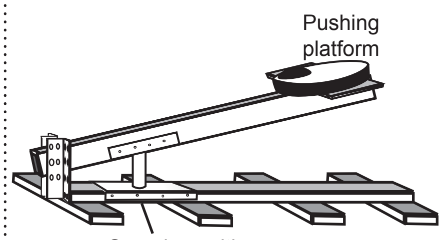
Initial ____________ Date ____________

Test and Evaluate

You will not be able to test the concrete with your hands as you did with the rolls of paper. You will need a test apparatus that can apply a much greater force: a "concrete crusher." Only one concrete crusher will be needed for the whole class; teams will take turns using it. Here's how to use a concrete crusher to test a concrete column.

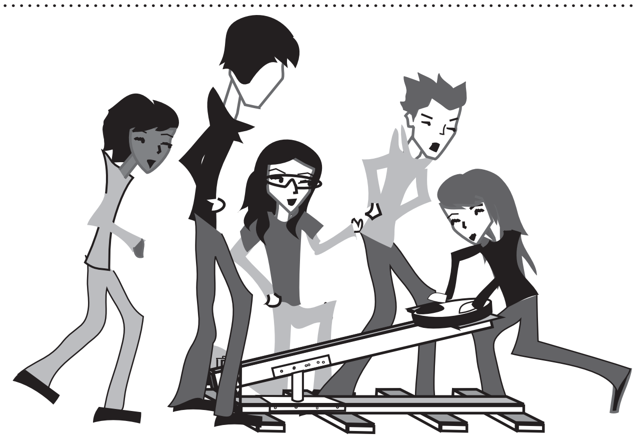
1) Place the scale at the sample position to measure the dead load of the weight of the lever arm. If the arm does not meet the scale, use a small block to level it out so that it is resting on the scale. Record the dead load weight at the bottom of the page.

2) Move the bathroom scale to the top the "pushing platform."



3) Position team members as follows:

- One person stands on the base near the hinge so it does not lift upward during the test.
- One person places his or her hands on the scale, ready to push down.
- One or two people watch the dial on the scale.
- One or two people crouch down to watch the sample. They should not stand too close so they are not injured by flying bits of concrete when the sample fails.



Safety Note: The person crouching down to watch the sample should wear goggles to prevent possible eye injury.

4) When everyone is in place, the person pushing on the scale will push with gradually increasing the applied force until the sample begins to crack or crush. That is the failure point.

5) Each team member should record how many pounds of pressure were exerted on the concrete crusher to reach the failure point. This is the applied force at failure. Record applied force below.

6) Each team member should draw a diagram of what the sample looks like when it just begins to fail. What is the failure site? What is the failure mode? (In other words, where and how did it fail?) Inspect the sample carefully and try to determine why it failed at that spot and in that way. Insert the drawings at this point in the *Engineer's Notebook*.

Dead Load Weight

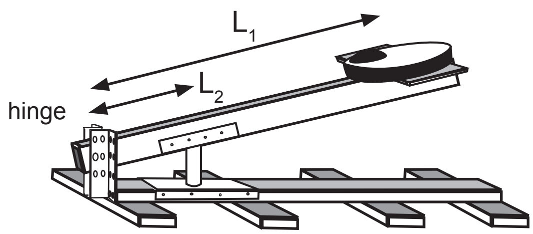
Applied Force at Failure	
Sample 1	
Sample 2	

Calculate Column Strength

The reading on the bathroom scale is not the same as the force on the sample, because the long arm of the concrete crusher acts as a lever to increase the force. Calculate the actual force on the sample in pounds as follows.

1) **Dead load** = weight of lever arm
(You recorded the value for dead load on the previous page.) ______ lb.

2) **Mechanical Advantage** *(MA)*



$$MA = \frac{\text{Distance from hinge to where force is applied}}{\text{Distance from hinge to where column is placed}}$$

$$MA = \frac{L_1}{L_2} = \frac{\qquad}{\qquad} = \boxed{\quad}$$

3) **Live load** = applied force × mechanical advantage
(You recorded the values for applied force on the previous page. The mechanical advantage is the same for both samples.)

Live load Sample 1 ______

Live load Sample 2 ______

4) **Stress** = $\frac{\text{dead load} + \text{live load}}{\text{cross sectional area of column}}$

The cross sectional area of the column is πr^2. The r is the measure of the column's radius or half the distance across the column.

Stress Sample 1 ______

Stress Sample 2 ______

Example:

The weight of the lever arm is measured at 20 lb. Applied force on the scale at failure is 50 lb.

Distance from the hinge to where force is applied is 90 in.

Distance from the hinge to where the sample is placed is 9 in.

The radius (r) of the column is 0.5 in.

1) Dead load = 20 lb.

2) MA = 90 in. / 9 in. = 10

3) Live load = 50 lb. × 10 = 500 lb.

4) Stress on Sample = $\frac{500\text{ lb.} + 20\text{ lb.}}{\pi\,(0.5\text{ in.})^2} \approx \frac{520\text{ lb.}}{0.785\text{ in.}^2} \approx 662\text{ lb. per in.}^2$

Results

Strength is the maximum stress right before failure. What was the maximum stress (lb./in.^{2}) at failure on each sample?

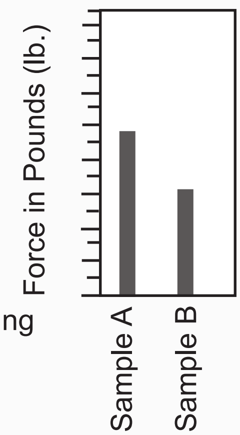
Maximum stress at failure on Sample 1 = ______ lb./in.^{2} Maximum stress at failure on Sample 2 = ______ lb./in.^{2}

Conclusion: What did you learn from this test about how to mix concrete for your foundation?

Communicate

Each team member should summarize the results of the test on one or two pages, and insert the results here. The summary should include the following:

- The names of all team members and the date
- A statement describing the composition of each sample, the variable that was tested, and all of the other conditions that were kept the same
- Your prediction about which sample would be strongest, and how much force you thought the strongest sample could support
- The total amount of force applied to each sample
- A bar graph comparing how much force each sample could withstand before failing
- A sketch showing the point of failure, and the appearance of the failed sample
- A conclusion of what you learned from the test



Redesign

In order to redesign the recipe for making concrete, you will need to think about your team's results as well as the results from all of the other teams.

1) Take notes while other teams report their results. Use the chart on the next page.

2) Discuss the following with your teammates:

Recall the problem: What were you trying to do?
Think about the results from all teams: What worked best? What does each ingredient do?

3) If you were in charge of the concrete-mixing crew for the foundation of a skyscraper, what instructions would you give to your team about how to make the concrete strong enough to support a huge building? Answer here.

4) If your team were asked to make a concrete mixture that was workable for a long enough time to make the perfect shape, how would you need to change the recipe? Answer here.

5) Research the term "steel-reinforced concrete." Briefly describe what it means and why it's used. Answer here.

Summary of All Results

What did each team test?	Sample Description	Max Stress at Failure	Conclusion
Team 1:	Sample A		
	Sample B		
Team 2:			
Team 3:			
Team 4:			
Team 5:			
Team 6:			
Team 7:			
Team 8:			
Team 9:			
Team 10:			

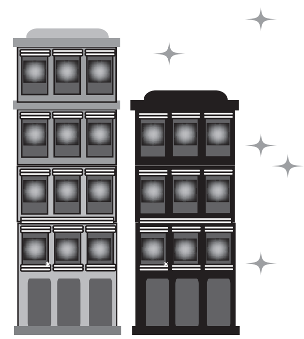
What is the best recipe for concrete with high compressive strength? How do you know?

Initial ______________ Date __________

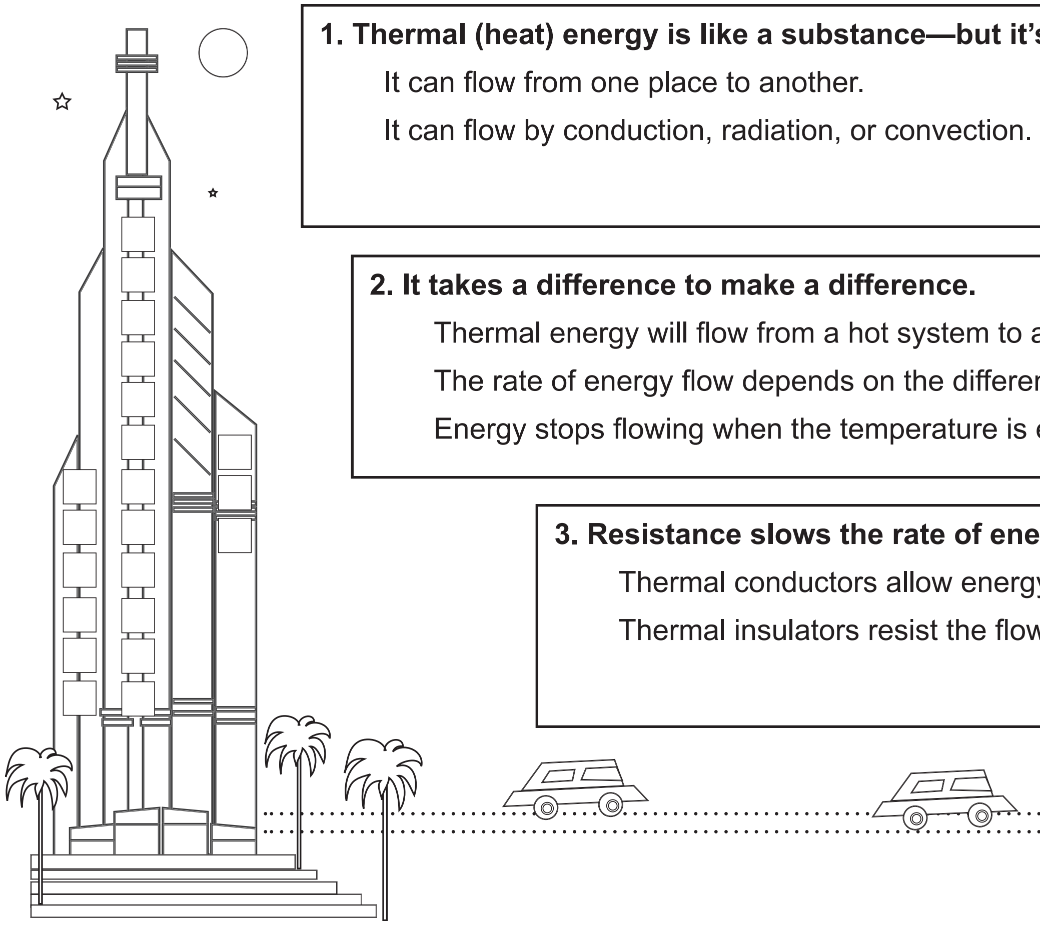
TASK 2.7 Make Your Building Energy Efficient

- Design an energy-efficient building.

Your multi-use building must provide a comfortable living temperature, hot water for washing, and a source of heat and light. However, it must also be as energy-efficient as possible to reduce the cost of monthly gas and electricity bills, and to lessen the impact on the environment. To design an energy-efficient building, you'll need to understand how to apply the three key ideas about thermal (heat) energy summarized below.



Key Ideas About Energy



1. Thermal (heat) energy is like a substance—but it's *not* a substance.

It can flow from one place to another.

It can flow by conduction, radiation, or convection.

2. It takes a difference to make a difference.

Thermal energy will flow from a hot system to a cool system.

The rate of energy flow depends on the difference in temperature.

Energy stops flowing when the temperature is equalized.

3. Resistance slows the rate of energy flow.

Thermal conductors allow energy to flow rapidly.

Thermal insulators resist the flow of energy.

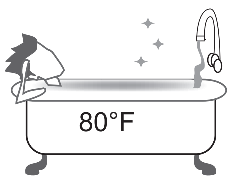
1. Thermal Energy Is Like a Substance

To avoid confusion with the common meaning of the word "heat," use the term **thermal energy.** Thermal energy is like a substance, as it can be stored and can flow from one place to another, but it is not a substance.

For example, a hot cup of coffee in an insulated cup will store thermal energy for a while. When it cools off it loses some of its thermal energy to the surrounding air. Thermal energy is not the coffee; it is something that you cannot see, but you can feel it if you spill the coffee while it still has a lot of thermal energy!

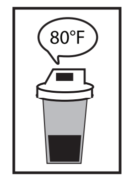
Thermal Energy vs. Temperature

Thermal energy and temperature are not the same!



Temperature: A cup of coffee and a bathtub full of water are both 80°F. Temperature does not depend on the amount of a substance.

Thermal energy: The bathtub water has much more thermal energy than the cup of coffee. That's because thermal energy depends on both temperature and quantity.



Test your understanding of this difference by taking the following self test. Answer the questions yourself, then compare answers with another student to see whether you agree.

Self Test

There are two cups of water.
The water in cup A is 50°F; the water in cup B is 100°F.

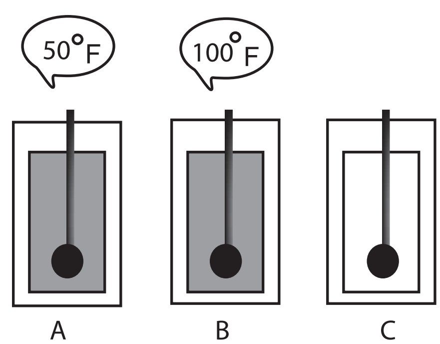
A. Which cup has more thermal energy (A or B)? ___

B. If you were to pour half of the water from each cup into cup C, what would be the temperature of cup C? ____

C. Which will have the highest temperature: A, B, or C? ____

D. Which do you think has the most thermal energy: A, B, or C? ____

E. Explain your answer to part D:



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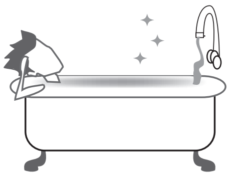
Flow of Thermal Energy

Thermal energy can flow in three different ways.

Conduction

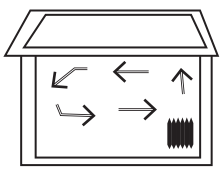


If two things are in physical contact with each other, and one is hotter than the other, thermal energy will flow from the hot object to the cooler object until they reach the same temperature. Think about slipping into a hot bath. Pretty soon your skin warms up until it reaches the same temperature as the bath water.

Radiation

Nearly all of the warmth on the Earth's surface comes from the sun. Thermal energy moves at the speed of light through empty space from the sun to reach you. Hold your hand on the side of a candle flame or next to a hot light bulb and you'll feel thermal energy radiated from the bulb.

Convection

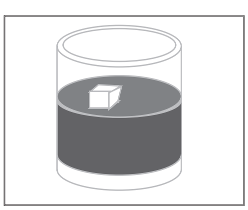


A room heater warms the air just above it. The warm air rises as cool air moves in to take its place. Pretty soon a current of air is set up in the room that moves thermal energy throughout the room. Similar currents are set up in a pot of boiling soup, carrying thermal energy from the bottom of the pot throughout the soup. Uneven heating causes convection in a gas or liquid.

Self Test: Work with a Partner

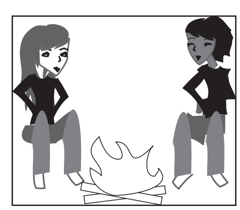
For each scenario, ask the following:

- What difference in temperature is causing heat energy to flow?
- Where is the heat energy coming from? Where is it going?
- Is heat flowing by conduction? Radiation? Convection? Or two or all three of these?
- When will heat stop flowing? Why will it stop?
- How can you predict what the final temperature will be?



Scenario 1:
An ice cube is melting in a glass of water.

Scenario 2:
You spill hot tea on your hand.



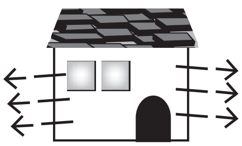
Scenario 3:
Warming yourself at a campfire.

Name ______________________________

2. It Takes a Difference to Make a Difference

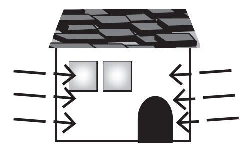
All systems have boundaries that define what's inside the system and what's outside the system. For example, the walls of a house define what's inside the house and what's outside.

If the temperature inside a system is hotter than the surrounding temperature, thermal energy will flow out. If the temperature outside is hotter, thermal energy will flow in. If you wait long enough, the temperature inside the house will equal the temperature outside, and energy will stop flowing.

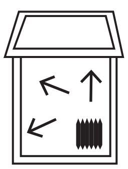


Cold day

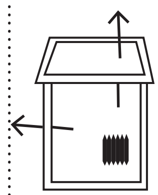
Arrows show which way thermal energy is flowing. On a cold day thermal energy flows out of the house; on a hot day it flows in. Energy stops flowing when the temperature inside and outside is the same.



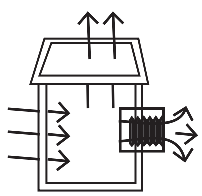
Hot day



To keep a house warm in winter, you need a furnace. Fuel for the furnace is an input to the system. The fuel has stored chemical energy that is released in the form of thermal energy when the fuel burns.



Thermal energy from the furnace warms the inside of the house, but some leaks out through the walls, roof, doors, and windows because there is a temperature difference. The furnace must burn fuel constantly because of this temperature difference.

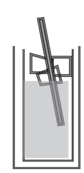


On a hot day people want the temperature inside the house to be cooler than outside. To do that requires input of electricity to run an air conditioner. An air conditioner pumps thermal energy out of the house. (Hold your hand on the outside of an air conditioner when it's running and you'll feel the heat coming out.)

Self Test

In the following sets of pictures, use arrows to show if thermal energy is flowing into or out of the system. All of these systems are surrounded by room-temperature air.

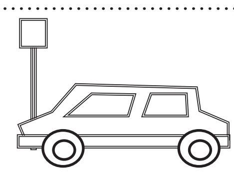
A very hot cup of tea



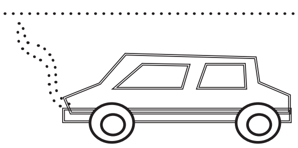
A glass of ice tea

Room-temperature tea

A popsicle



A car parked for several hours

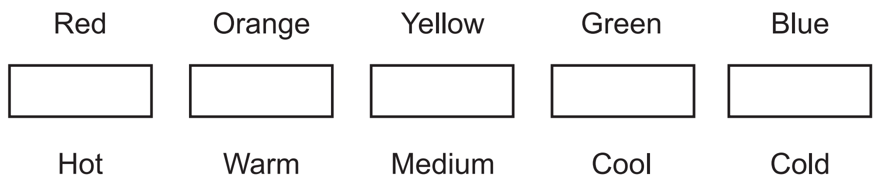


A car with its engine running

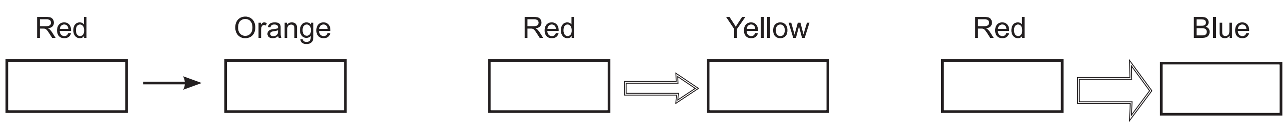
Initial ______________ Date __________

Color

It's helpful to diagram a system using colors to show how heat energy is distributed inside and outside the system. If you have a colored pencil or marker, color in these boxes, as indicated, to show a range of temperatures, from hot (red) to cold (blue). The colors will make it easier to see what's going on.



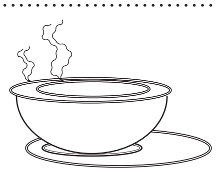
Arrows

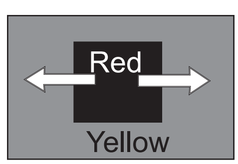


You can use arrows to show the direction that energy flows. The bigger the difference in temperature, the fatter the arrow should be.

Self Test

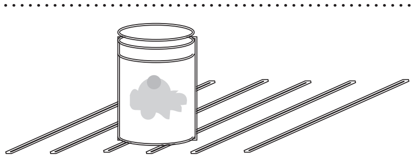
See if you can apply these ideas by creating diagrams to represent these systems. The first one is done for you. Use colors and arrows as indicated above.





A bowl of hot soup on the dinner table

A frozen popsicle on a really hot day



Frozen ice cream in the freezer

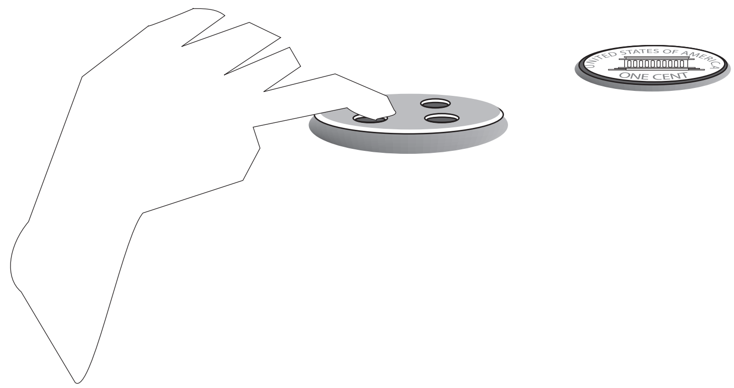
A hot cup of coffee on a really cold day

3. Resistance Slows the Rate of Energy Flow

Conductors and Insulators

There are times you want to speed up the flow of thermal energy, such as when you're cooking and everybody's hungry. And there are times you want to slow down the energy flow, such as when it's freezing outside. By choosing the right materials, you can speed up or slow down the flow of thermal energy. Usually, the choice is between a good conductor (such as metal) or a good insulator (such as layers of clothing).

If a plastic button and a penny are in a room for several hours, they will both be at room temperature. But when you touch them, the metal penny feels colder than the plastic button! Why do you think the metal feels colder than the plastic?



Flow Rate of Heat

Previously, you learned that the greater the temperature difference, the more rapid the transfer of thermal energy. It is also true that thermal energy transfer can be slowed down by placing an insulator at the system boundary. These two ideas can be expressed as the following equation:

$$\boxed{Q = \frac{A \Delta T}{R}}$$

Q = the rate at which thermal energy flows

A = the area through which energy flows

ΔT = the difference in temperature ($T_{high} - T_{low}$)

R = "R value" is a measure of the resistance of the material to the flow of thermal energy for a given thickness

Self Test

1) If ΔT (difference in temperature) increases, what happens to Q (flow of energy)?

2) If R (resistance of the medium) increases, what happens to Q?

3) If A (area through which energy flows) increases, what happens to Q?

Initial ______________ Date ___________

Resistance of Various Materials

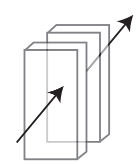
When designing your building, you can choose a material for the walls with a high R-value to slow the transfer of energy through the walls. That will help you conserve energy, burn less fuel, and save money. You can find the R-values of various materials in an R-value table. These tables are created by testing materials to see how well they insulate. Here is a sample table of R-values that lists some of the most common materials used in building.

Table of R-Values

	Construction Material	**R per thickness**
Wall Materials	Plywood sheathing (5/8)	0.77
	Brick 4 face	0.44
	Concrete block 4 face	0.80
Roofing Materials	Wood shingles	0.97
	Asphalt shingles	0.44
Windows	Single glass	0.91
	Double insulating glass with 1/4 air space	1.69
Air Spaces	1/2 to 4	1.00
Insulation Materials	Fiberglass batt	3.14
	Fiberglass 1 in wall	3.20
	Rock Wool batt 1	3.14
	Cellulose 1 in wall	3.70

Total R-Values

If you use double the thickness of the same material, the R-value will be double. For example, the R-value of one 4" brick is 0.44, and the R-value of two 4" bricks is 0.88. Similarly, the R-values of any two or three materials will add to make up a total R-value, which is symbolized as R_T.



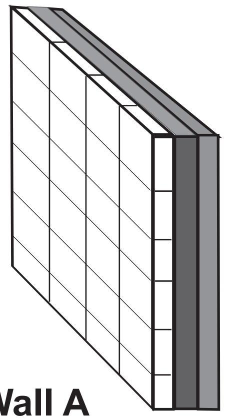
$R_T = R_1 + R_2$

1) On a separate sheet of paper, sketch a possible design for the walls of the building that you will design. Show a side view of the wall materials and calculate the total R-value. Insert the paper at this point in your *Engineer's Notebook.*

Read Chapter 15, "Building Green," in the textbook *Engineering the Future,* in which architect Chris Benedict describes the problems with conventional heating systems and explains how she designs energy-efficient buildings. Use notebook paper to answer the questions at the end of the chapter. Sign, date, and number each page. Insert the pages at this point in your *Engineer's Notebook.*

Name ______________________________

Comparing Total R-Values

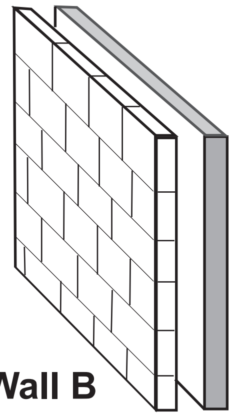


Wall A

Outside: concrete block 4 face

Middle: 1 cellulose

Inside: 5/8 plywood sheathing



Wall B

Outside: brick 4 face

Middle: 1 air space

Inside: 5/8 plywood sheathing

1) Calculate R_T for Wall A =

2) Calculate R_T for Wall B =

3) Which do you prefer and why?

Thermal Energy Transfer Equation

In the English system, the rate at which energy flows through a surface *(Q)* is measured in **British Thermal Units** (BTU) per hour.

$$Q = \frac{A \Delta T}{R}$$

1 BTU is the amount of thermal energy needed to raise one pound of water one degree Fahrenheit (1°F). It is about the amount of thermal energy in one kitchen match.

In the space below, use the thermal energy equation to find the rate of energy flow through each of the two walls above if the area of each wall is 10 ft.^{2} and it is 5°F above zero outdoors and 65°F indoors. Be sure to write your answer in BTU/hr.

1) For Wall A $Q = \frac{A \Delta T}{R}$

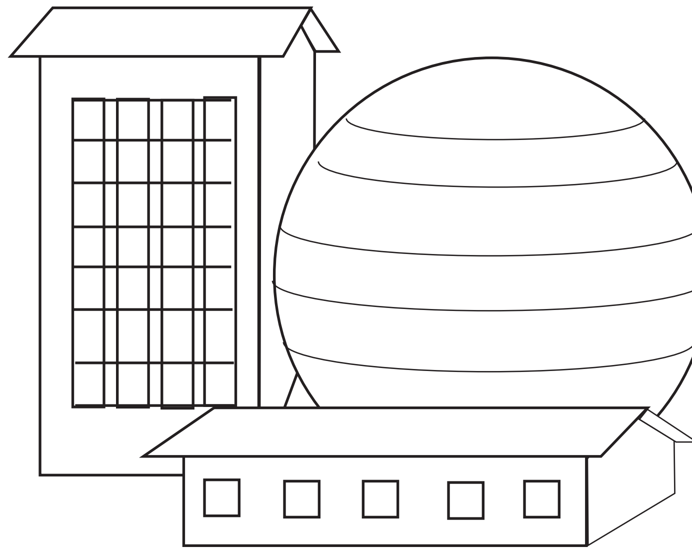
2) For Wall B $Q = \frac{A \Delta T}{R}$

Initial ______________ Date __________

Designs for Energy-Efficient Buildings

Insulating walls is not the only thing you can do to design a more energy-efficient building. Here are some additional suggestions. Look at the ideas on these two pages, then create your own ideas.

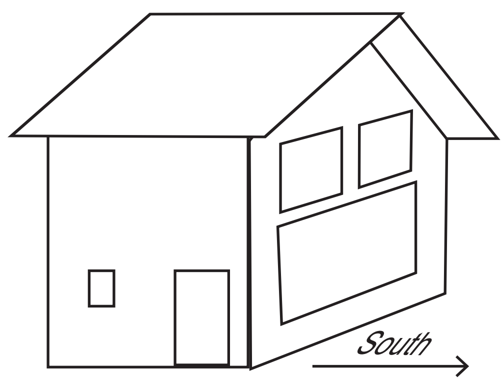
1) **Shape.** The rate at which thermal energy flows depends on area. Some shapes, like spheres and cubes, have less wall area for the same internal volume, than do long flat shapes.



2) **Color.** Light colors reflect more of the sun's radiation; light-colored buildings reduce the need for air conditioning in summer. Dark colors absorb light, so a dark-colored building requires less heating in winter.

3) **Size and number of windows.** Large windows reduce the need for electric lighting. However, they lose thermal energy much faster than a solid wall. So the number and size of windows is a trade-off.

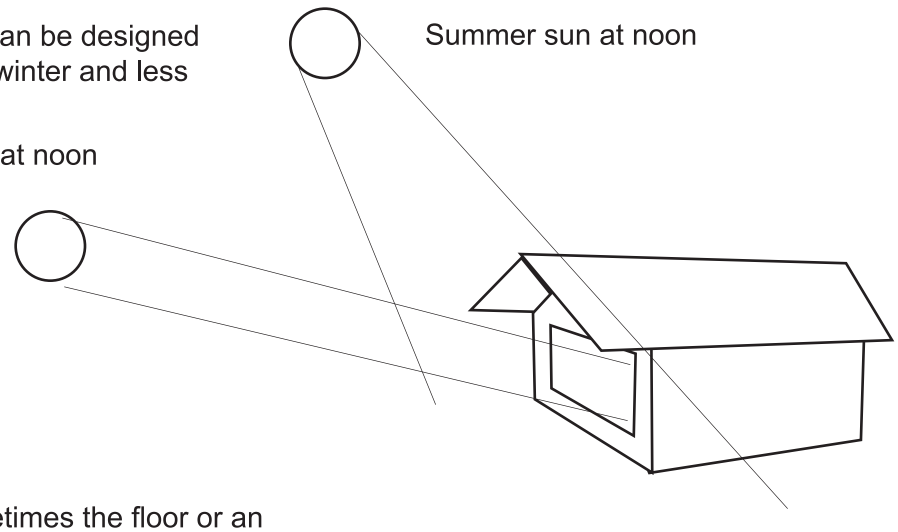
4) **Location of windows.** In the Northern Hemisphere, the sun's highest point in the sky around noon is toward the south. Placing windows on the south side of the house allows more light to enter in winter.



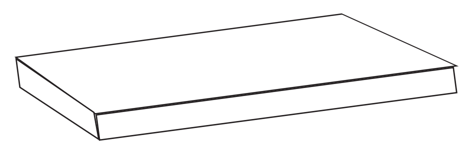
Name ______________________________

More Energy-Saving Ideas

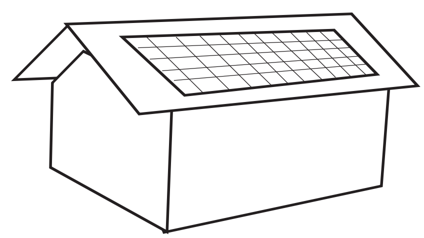
5) **Shade.** Roof overhangs can be designed to admit more sunlight in winter and less in summer.



6) **Thermal reservoir.** Sometimes the floor or an internal wall of a house is built from stone or concrete or some similar material. These absorb and store heat during the day, then gradually release it at night, so the heater needs to do less work.



7) **Solar power.** Solar cells and even windmills can be added to a design so it meets more of its own energy needs.



On a separate sheet of paper, sketch some ideas of your own that combine two or more of these suggestions for an energy-efficient building. Think about how big you want it, what features you want it to have, and what it will be like for people who live in it. Put your name and date on your sketches and insert them here.

Read Chapter 16, "A Race for the Sun," in the textbook *Engineering the Future,* in which college student Lauren Stencel describes a home she is building that uses the sun for most of its energy needs. Use notebook paper to answer the questions at the end of the chapter. Sign, date, and number each page. Insert the pages at this point in your *Engineer's Notebook.*

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DESIGN CHALLENGE

Test Insulating Materials

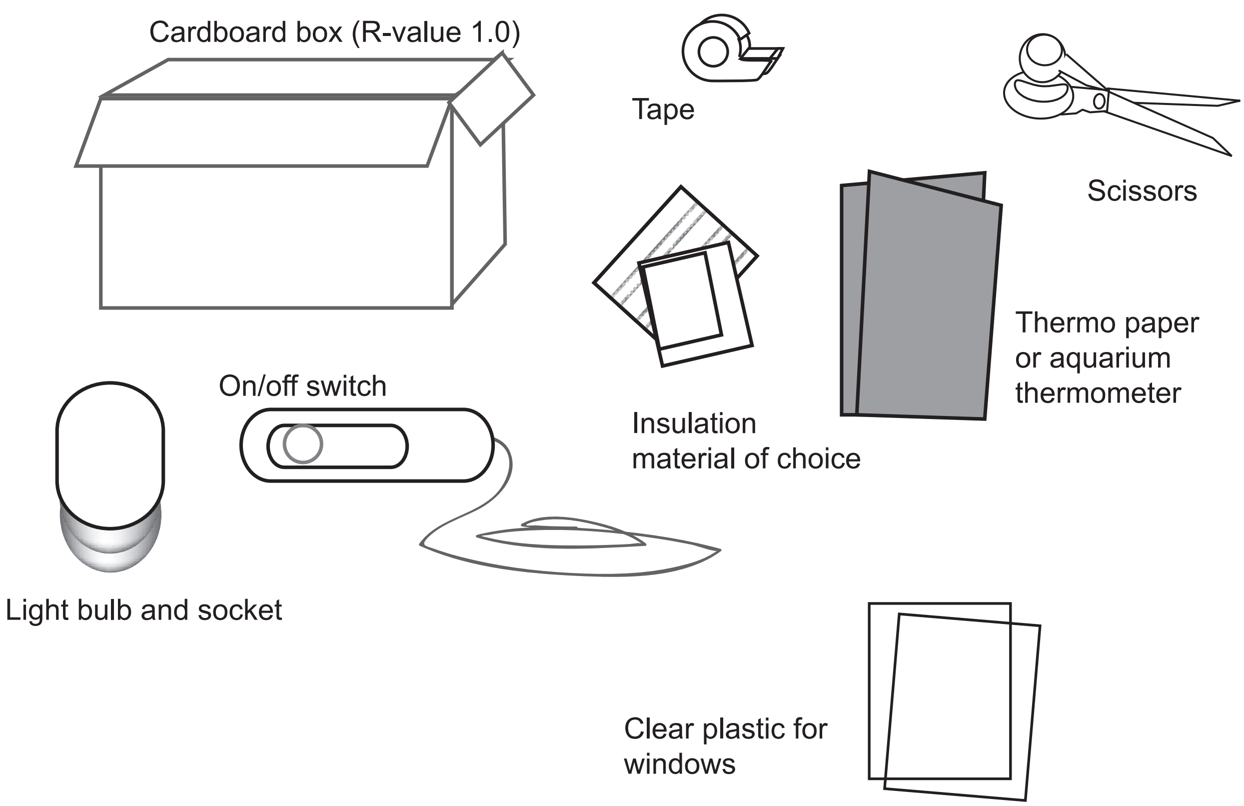
In the previous tasks you learned how thermal energy will move across system boundaries when there is a difference in temperature. If energy is transferring into a system, it's called heating. If energy is transferring out of a system, it's called cooling. In either case, you want to use insulating materials to slow the flow of heat energy across the system boundary.

The challenge for your ETF team is to test insulation materials to see how well they reduce cooling and keep a home warm. You will design a box to test insulation materials.

Your design should include:

- A hole for the heat source (light bulb)
- Window openings for thermo paper or clear plastic so you can read a thermometer inside
- Insulating material of your choice with thickness and R-value recorded

What You Will Need



Procedure

1) To determine how well your model home maintains an even temperature even when it's cold outside, set it up with insulation on all walls, heat source (light bulb), windows (clear plastic), and thermometer or thermo paper. Do not place materials directly against the light bulb.

2) At the start of the test the temperature inside and outside the model home will be the same. Record this temperature.

3) Now turn on the heat source and record the temperature inside the home every minute. The temperature inside the home will start to climb.

4) Stop recording when the temperature inside levels off, which is when the temperature inside stays the same for three minutes.

5) Record these measurements on a sheet of graph paper. Be sure to label the axes. "Time" should be on the horizontal axis (at the bottom) and "Temperature" should be on the vertical axis (on the side).

Lab Report

Prepare your lab report on notebook and graph paper and insert it here. Be sure your report includes the following:

1) Explain why you chose those insulation materials and how you used them to insulate the box.

2) List the R-values for your materials and describe how effective they are as insulators.

3) Draw a diagram to show how the heat energy flows through your "house."

4) Use the thermal energy transfer equation to find the rate of energy flow when the inside temperature levels off. (Be sure to count the area of all sides of the box.)

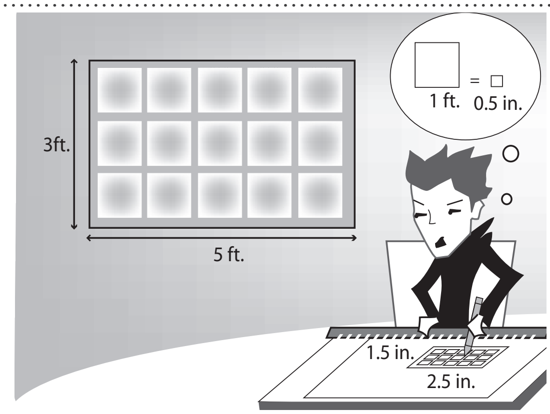
5) Attach a graph showing how the temperature inside the house changes when the heat source is turned on, until it reaches a steady temperature.

6) Write a conclusion about the effectiveness of the insulation materials you tested, and what you might do if there is time for a second experiment to further increase their effectiveness.

TASK 2.8 Make a Scale Drawing of Your Building Design

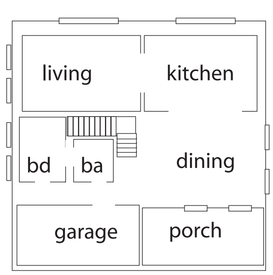
- Learn how different methods of drawing and models are used in building design.

After you have designed your multi-use building, you will have to communicate your idea through a plan and a scale model. A plan is a two-dimensional scale drawing. This means that lengths on the plan are in the same proportions as in the structure itself, only smaller. For example, if a window is 3 ft. × 5 ft. in a building on a plan in which 1/2 inch = 1 foot, the drawing of the window would be 1.5 in. × 2.5 in.



Scale Drawings and Models

- **Plan views** are drawn as though the ceiling and roof are removed so you can look down at the floor.
- An **elevation** is a scale drawing of the front of a building.
- A **scale model** is a three-dimensional structure, often made from cardboard or wood. As soon as you have made a plan for your building, it will not be difficult to use the plan to construct a scale model.
- A **footprint** of a building is a plan drawing of only the exterior walls.



Plan view

Elevation view

Scale model

Finding Dimensions

Below is a floor plan of the first floor of a house. It is a scale drawing in which 1 inch on the drawing is equal to 8 feet in the actual house. Use a ruler to measure the drawing and answer these questions.

1) What is the length and width of the living room? __________

2) What is the area of the living room? __________

3) What is the length and width of the dining room? __________

4) What is the area of the dining room? __________

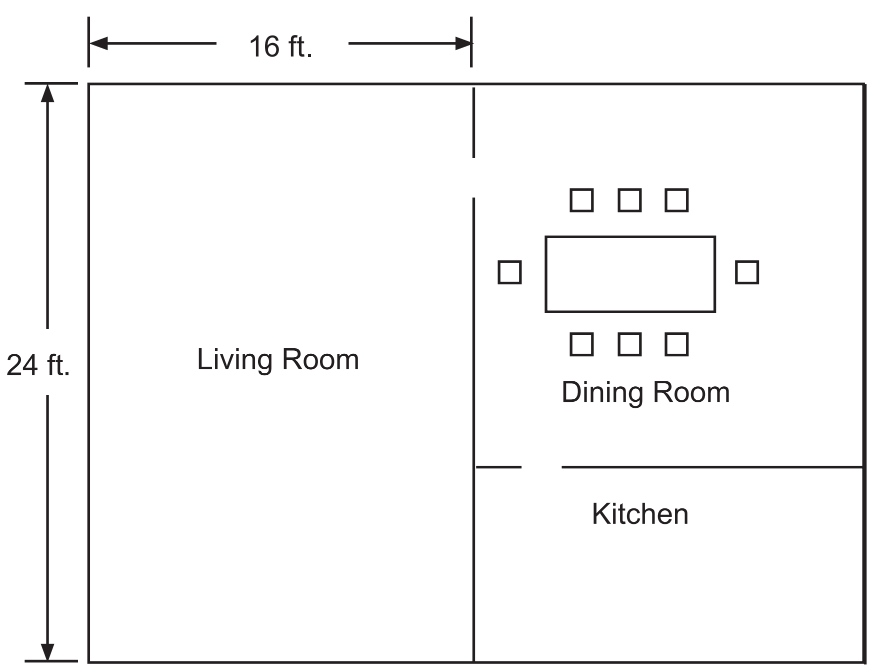
5) How long and wide is the table in the dining room? __________

6) What size are the chair seats in the dining room? __________

7) What is the "footprint" (area) of the entire house? __________

8) Dimensions on plan drawings are shown with arrows, as illustrated for the length and width of the living room. Add arrows and numbers to indicate the dimensions of the dining room and kitchen.

9) Notice the title block on the lower right of the paper, at the bottom of the scale drawing of the floor plan. The title block names the drawing and gives the scale, the name of the person who drew it, and the date. All engineering drawings should have a title block.



Floor Plan	Scale 1:96
Johnny Jones 10-9-07	

Initial ____________ Date __________

Make Your Own Scale Drawings

1) Use the space below to make a scale drawing showing a **plan view** of an apartment with a scale of 1 inch = 10 feet (or 1 in. : 120 in.). The apartment has the following dimensions:

> The length and width of the apartment are each 40 feet.
> The kitchen is 20 feet by 15 feet.
> The living room is 40 feet by 20 feet.

2) The rest of the area on this floor is taken up by the **dining room.**

A. What are the length and width of the dining room in the scale drawing? _____________

B. What are the length and width of the dining room in the actual apartment? _____________

3) What is the area of the kitchen

A. in the scale drawing? _____________

B. in the actual apartment? _____________

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Your Classroom

On a separate sheet of graph paper, practice your scale drawing skills by making a plan view of your classroom, as follows:

1) Measure the length and width of the room by walking the distance and counting your steps. Convert to feet.

2) Decide on a scale so that you can fit your drawing on this page.

3) Draw the walls of the room first using a ruler. Show a doorway as a break in the line representing the wall.

4) Make a title box at the bottom right of the page to write in the title, scale, your name, and date.

5) Measure the sizes of any chairs, desks, or tables in the room, and show these with the correct scale on your drawing. Add a page showing your measurements and calculations to determine the sizes of objects in the drawing. Insert your scale drawing and page of calculations at this point in your notebook.

On your final project, described in the next section, you will apply everything you learned in this project to design a multi-use building and make scale drawings of your design. Your drawings will be evaluated using a rubric like the one below. How would you score your own scale drawing of your classroom using this rubric? ______________

Rubric for Scale Drawing

	✦✦✦	✦✦	✦
Scale Calculations	Scale shown on drawings as well as dimensions of major rooms. Calculations of several important features are given on a separate sheet of paper. No math errors.	Scale shown but few dimensions or calculations given. No major math errors.	No scale or calculations given.
Drawing Mechanics	Straight edge was used. Important features are labeled. The drawing is appropriately sized and neat.	Some edges are straight and the page is somewhat neat. The drawing could be adjusted to better fit the page.	Little effort in the neatness. Little use of straight lines and/or the drawing is not appropriate for the page.
Requirements	Completion of all requirements including plan views of all floors, front and side elevation drawings, and footprint of building.	Completion of most requirements.	Partial completion of requirements with little effort.

Initial ______________ Date __________

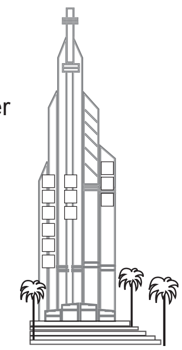
TASK 2.9 Design a Building of the Future!

- Use all the skills you have learned about engineering and building.
- Design a building and construct a model of it.

Now it's time to put everything you've learned to work as you design a building of the future. You will work on a design team of up to four people. The challenge is to create a building that will reduce urban sprawl. You and your team will make sketches, scale drawings, and a three-dimensional model, and give a presentation to inform clients (your classmates) of your design ideas.

Clients will be looking for a design of a single structure that includes the following:

- An area where people live
- A place where a business, factory, or other activity can take place
- An original and attractive shape
- A strong foundation
- A structural design that will support the estimated live load
- A means for heating in cold weather and cooling in warm weather
- Features that make the building energy efficient



DESIGN CHALLENGE

Define the Problem

Think of a place in your community where a multi-use structure might be built, and what types of service or products you think people in your community might be willing to pay for.

Then do the following:

Problem Statement

Write a problem statement, which is a short description of the functions of the building that you think are needed, such as "Design a building that houses up to four families and a workshop for creating greeting cards." Each team should have a different problem statement.

Criteria

List criteria for a successful design. You may want to include some of the ideas on the previous list, or look up urban sprawl in the library or on the web, to see what other features it may have.

Constraints

List constraints (limitations). Cost is almost always a factor, but sometimes there are other constraints, too. For example, it may need to fit into a certain space, or it may need to accommodate people in wheelchairs.

Research the Problem

- Talk with people in your community to see what kinds of businesses are needed, and how many people should be housed in your building.
- Consider whether garage spaces should be included, or other services such as health and fitness facilities.
- The zoning code in your community may not allow multi-use buildings. If so, you may have to get special permission, called a “variance,” from your community government. Ask your City Clerk for more information on zoning codes and how to request a variance.
- Estimate the live loads your building must support, and decide on a safety factor.
- What construction materials are available locally?

Develop Possible Solutions

- After the team has defined the problem and researched the need, each individual should think about how the building might be shaped so that it meets all of the criteria and constraints. Draw sketches of these ideas.
- Sketches do not have to be drawn to scale; they just have to show the general idea. Include these sketches in your *Engineer’s Notebook.*

Choose the Best Solution

- Team members should take turns sharing their sketches with the rest of the team and then discuss the pros and cons of various ideas.
- Look for ways to incorporate the best ideas from two or three different designs.
- The best idea may be obvious to everyone; if not, you may want to create a Pugh chart as described in Project 1 to help you decide.

Create a Prototype

- First create scale drawings of your structure. Create both floor plans and elevations. If different things happen on different floors, you will need a plan drawing for each floor. If your building will include several apartments, you may want to create a scale drawing of one of the apartments as an example.
- Use the plan and elevation drawings to build a 3-D model of the designed building with cardboard and tape or glue. You may want to use a pen to mark doors and windows.

Test and Evaluate

- Look back at your problem definition. How well did you meet the criteria and constraints of the problem?
- What might you want to change now that you see what the model looks like?
- Remember, you can always go back and change the problem definition if it makes sense to do that, given how your team’s ideas have changed.

Initial ______________ Date __________

Communicate

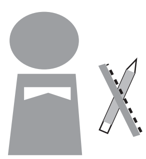
- Each member of the team should write a report in his or her own words to communicate how your team designed this building.
- Each team member may want to include a copy of the engineering drawings for the building, but individuals should describe each step of the process in his or her own words.
- Before starting your report, look at the rubric on the next page to see how your report will be evaluated.

Benchmark

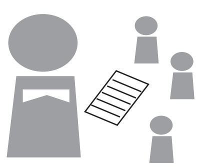
Congratulations!

You have learned how to design safe, strong, and creative buildings to help solve the problems associated with urban sprawl.

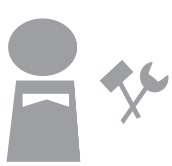
In the construction industry you will find that work of this sort is divided among many people with different capabilities who must all work together as a team. These include the following:



Architects who make the initial designs and work with engineers to refine the plans and with contractors who are responsible for building the structure.



Contractors hire technicians with a variety of skills to dig the foundation; mix and pour concrete for the foundation; construct the frame, walls, and roof; install electrical wiring, water and drain pipes, ventilation systems, floors, the furnaces and air conditioners, and, of course, the doors, windows, and internal surfaces.



Technicians of various sorts, including carpenters, electricians, plumbers, and roofers who do the actual constructing.

Although many people with different skills are involved in the process of designing and constructing buildings, the engineer's work is not finished until the building passes its final safety inspection.

If, someday in the future, you should become involved in the construction industry, what role would you most like to play?

Rubric for Design a Building of the Future

	⌖⌖⌖	⌖⌖	⌖
Define the Problem	Problem clearly defined with list of criteria and constraints. Detailed list of research information, websites, pictures, and descriptions of example buildings. At least 3–5 different building ideas.	Good definition of problem, with criteria and constraints. Some research notes. Three or four different building ideas, but not much variety.	Minimal definition of problem, poor list of criteria and constraints. Very little research. One or two different ideas.
Create Scale Drawings	Floor plans show different uses. Scale is accurate and the drawing fits the paper size. Building elements labeled, important dimensions shown, and the title block is neat and complete.	Floor plans do not show different uses of rooms. Missing labels and dimensions. Title block and margin are present but missing data.	Little evidence of a clear floor plan.
Analyze Loads	Live and dead load analysis shows logical thought process. Forces on structure are described accurately.	Dead load and live loads are identified, but little analysis of forces in main members.	No attempt at analysis of live and dead load.
Design Structure	Substantial reasoning given for choice of shapes that reflects a consideration of size, dead and live loads, interior space, and exterior influences.	Reasoning given for choice of shapes that reflects only some consideration of size, dead and live loads, interior space, and exterior influences.	Report does not mention any consideration of appropriate shapes or design for strength.
Energy Efficiency	Report describes several energy efficient features and illustrates how thermal energy flows through the building.	Report describes several energy-efficient features but does not describe how or why they save energy.	Report includes very little or no mention of thermal systems.
Communicate Clearly	Drawings and model provide clear description of building design. Writing is clear and well-organized. Description of design process is thorough and easy to read.	Drawing and model are adequate. Writing is fairly clear and organized. Most requirements are met.	Some attempt at drawing and model, but poorly made. Presentation is disorganized and some requirements lacking.
Teacher Comments			**Total Points:**

Initial ____________ Date __________