GUIDANCE FOR TEACHERS

Hofstra University Center for Technological Literacy

Simulations and Modeling for Technology Education

This Project is funded by a grant from
the National Science Foundation
Grant # 0821965

EMERGENCY SURVIVAL SHELTER DESIGN ACTIVITY
Guidance for Teachers

OVERVIEW OF THIS DESIGN ACTIVITY

This activity will invite your students to undertake the design of an emergency survival shelter. It is targeted to eighth grade students who have had some previous exposure to introductory algebra. This overview provides a snapshot of the activity. Attached to this overview are student activities (knowledge and skill builders or KSBs) that will help your students gain the information and skills they need to design and build their survival shelter.

PROBLEM SITUATION: *Here's the problem situation that your students are asked to consider:*

TO BE UNDERSTOOD BY STUDENTS:

You and three others are competing to become part of an elite team known as the Survival Masters. Survival Maters are highly skilled survivalists who help when natural disasters strike. The competition is taking place in a remote area of Alaska. Shortly after arriving, an earthquake strikes and destroys buildings, wrecks power lines, cracks the airport runway, damages roads, and triggers a landslide. Even the tent you were using has been ripped to shreds by falling debris. You are cut off from civilization except for the battery operated radio equipment that you have brought with you.

DESIGN CHALLENGE: *Here is the design challenge your students are asked to undertake. It will require them to apply their science, technology, engineering, and math (STEM) skills.*

TO BE UNDERSTOOD BY STUDENTS:

You and your fellow contestants are 200 miles from the nearest city and the earthquake has made travel impossible. You must work together as a team to build a shelter to keep you warm during the time it will take for a rescue team to reach you.

With temperatures below freezing, your challenge, as one of a team of earthquake victims, is to design and build a rapidly erectable structure that will provide insulation from the cold, withstand the weight of snow (snow load) and the force of wind (wind load); and be built from materials that are readily available locally.

HERE ARE SAFETY RULES THAT YOUR STUDENTS SHOULD ABIDE BY:

1. Only use tools and machines only after proper instruction.
2. Wear eye protection when using tools and cutting materials.
3. Be sure that any testing of models is done under teacher's supervision.

DESIGN SPECIFICATIONS: *Please convey to students that **specifications** are the performance requirements that a design solution must fulfill. These are the design specifications that your students will have to meet.*

TO BE UNDERSTOOD BY STUDENTS:

- We can assume a daytime temperature high of 65° F and that temperature will fall drastically once the sun goes down.
- The shelter must be kept at an inside temperature of at least 45° F when the outside temperature drops to 25° F. Lower than that, hypothermia will set in even if the team members are wearing jackets.
- The only heat source available is the body heat of the four team members.
- The shelter must be large enough for all four survivors to sleep side by side and sit up comfortably within it.
- The shelter must sustain a 15 mile per hour wind and a snow load of six pounds per square foot.

DESIGN CONSTRAINTS: *Constraints are often related to the kinds of materials you can use, how much time is available, and in many cases, how much money the finished design can cost. In this case (because the students are in a survival mode) cost is not as important as it might otherwise be. Here are the constraints (the limitations) that your students will have to work within.*

TO BE UNDERSTOOD BY STUDENTS:

Your team may use only the materials found at the earthquake site to build the shelter. These include natural materials (such as spruce trees and boughs) and items that were stored in the team's tent including plywood, 2 x 4s, fiberglass fishing poles, fiber glass and Styrofoam insulation, newspaper, corrugated cardboard, plastic (polyethylene) tarps, canvas, rope and twine, duct tape, hardware, and hand tools.). The team may use other materials provided by the instructor. The shelter must be built in one 10-hour day (equivalent to about fifteen 40-minute class periods), or survivors will be at risk of hypothermia.

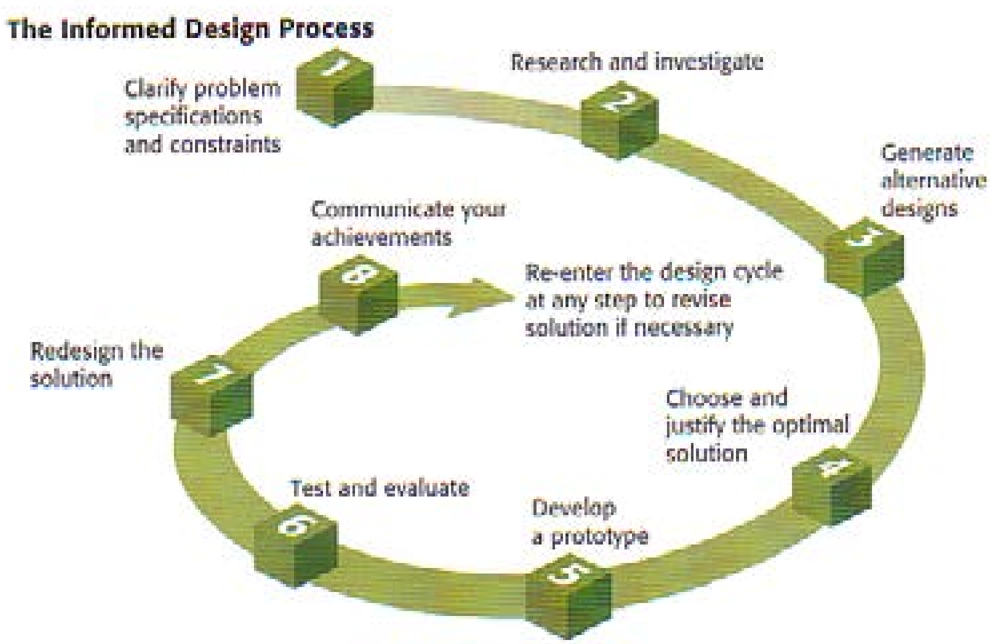
INFORMED DESIGN - THE PEDAGOGY BEHIND DESIGN

Informed design, a design pedagogy developed and validated through several NSF projects conducted by the Hofstra Center for Technological Literacy, prompts research, inquiry, and analysis; fosters student and teacher discourse; and cultivates language proficiency. Students acquire knowledge to inform their understanding before they begin designing. Student design teams will clarify specifications and constraints; conduct research; generate alternatives; justify the optimal design; test, evaluate, and modify the solution; and communicate achievements in a class presentation and final design report.

To provide the foundation for informed design activity, we engage learners in a progression of knowledge and skill builders (KSBs) – short, focused activities designed to teach salient concepts and skills. KSBs prepare students to approach the design challenge from a knowledgeable base and provide evidence for assessing understanding of important ideas and skills. As background for design activity, KSBs enable students to reach informed design solutions, as opposed to engaging in trial-and-error problem solving where conceptual closure is often not attained. In this project, KSBs have been developed to introduce students to important concepts and skills.

PHASES OF THIS *INFORMED DESIGN* ACTIVITY

There are seven phases to this informed design activity. These phases will be explained on the pages that follow.



They include:

1. Research and investigate
2. Generate alternative designs
3. Choose and justify the optimal solution
4. Develop a prototype
5. Test and evaluate your design
6. Redesign the solution
7. Communicate your achievements

PHASE I: RESEARCH AND INVESTIGATE

Phase I of the design activity is for students to research and investigate ideas that will help them build their knowledge and skill base. Once they do so, they can approach the design challenge from a more informed perspective. During this phase, they are asked to complete a series of Knowledge and Skill Builder activities (KSBs). Completing the KSBs will take about 15 class periods.

Here's a list of the KSBs students will be expected to complete:

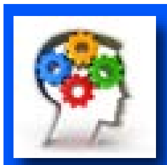
- Knowledge and Skill Builder I: Surface Area and Volume Calculations
- Knowledge and Skill Builder II: Conductive Heat Flow
- Knowledge and Skill Builder III: Relationship between k Value and R Value
- Knowledge and Skill Builder IV: Structural Design

It is important to remember that students should refrain from starting to design their survival shelters, without first completing the KSBs. The KSBs will prepare them to approach the design challenge with more of a knowledge and skill base, and evolve better design solutions.

PHASE II: GENERATE ALTERNATIVE DESIGNS

There are numerous ways in which to approach the design of an emergency shelter. It is best if students work in groups of four where there is collaborative problem solving and shared learning. Group members will assist each other in choosing the type of shelter they wish to design and model and in teams, with your help, they should think about various ways to design and make the shelter.

You might ask your students to sketch at least three possible versions of a shelter that might satisfy the design criteria and constraints. In their sketches, they should clearly illustrate the shape of the structure, show the type of frame they would use to support it, show a method for anchoring the structure so that it will not move when subjected to wind load, and identify the materials from which the shelter will be built. They should also be sure to detail the size of the shelter (the floor area and the inside volume of the shelter).



Once the students complete the first KSB (Surface area and Volume Calculations) they will be prepared to make design decisions about the shelter's size and shape. After completing KSB 2 (Conductive Heat Flow), your students will be familiar with the way heat flows from hot to cold through a material's surface, and how a material's composition (its thermal conductivity or *k* value) and thickness affect the rate of heat flow. The concept of R *value* and its relationship to a material's thermal conductivity and thickness is the focus of KSB 3; and in KSB 4, students will learn about how to design a structure to ensure its stability. and structural integrity.

PHASE III: CHOOSE AND JUSTIFY THE OPTIMAL SOLUTION

After the students complete the KSBs and agree on a shelter design, they should document their thinking and decision making. They should do so by writing about the decisions they reached that guided their choice of shelter design in a design journal. They should explain why their group settled on a particular design, and note the tradeoffs their team had to make in coming to the decision that they did.

Note: Some hypothetical tradeoffs could be:

- Using materials that are readily available although they may have less structural strength than materials that have to be retrieved from a distance;
- Using materials that are easier to work with, but have higher thermal conductivity;
- Making a shelter from a simpler shape because it's easier to build, but would have more surface area and higher heat loss.
- Making a shelter from a simpler/larger shape because it's more comfortable, but would have more surface area and higher heat loss.

PHASE IV: DISPLAY THE SHELTER MODEL

After the students complete the KSBs and do their designing as a team, they should model their shelter. The model can be a full size version, or it can be a scale model. Discuss with the students whether they should attempt a full size design or a scale model.

Whatever you and your students decide, the shelter must actually work to limit the heat flow from inside the shelter to the outside environment and stand up under load. When the students display their finished model, they should be sure to show all the calculations and drawings that they did while designing their shelter.

PHASE V: TEST AND EVALUATE

In this phase, the students will test their shelter and evaluate their success. They should prove that their shelter works by showing the heat flow calculations that indicate if the shelter indeed will maintain an interior temperature of at least 45° F when the outside temperature is 25° F. They should also show how they tested the shelter's ability to withstand wind and snow load. KSBs 3 and 4 will prepare them to do this.

If your school is in a cold climate, you might wish to test the heat flow characteristics of the shelter outdoors. Otherwise, your students can make a model of the shelter and test its heat flow characteristics by placing it in a freezer or a refrigerator. You can simulate wind load by using fans or putting a shelter model in a wind tunnel; you can simulate snow load by placing a weight on top of the shelter.

PHASE VI: REDESIGN THE SOLUTION

In this phase, students should be encouraged to think about what they learned through the design and/or testing of their shelter and think about how they would make changes to the design if they were to do the activity again. Ask your students to consider what additional tradeoffs (if any) they would have to make if they were to design their shelter differently.

PHASE VII: COMMUNICATE YOUR ACHIEVEMENTS

In this final phase, your students should plan and deliver a presentation about their design solution to the entire class. They should use a variety of media (PowerPoint, video, musical accompaniment, charts, photographs, etc.). It is often motivating for the students if they are asked to dress formally for their presentation.

In their presentation, each team should explain what they learned about surface area and volume, conductive heat flow, k and R values, and structural design. They should also demonstrate how they tested their shelter design.

KNOWLEDGE AND SKILL BUILDERS

Students will be asked to complete four knowledge and skill builder activities (KSBs) before they begin designing. The KSBs will provide students with the background knowledge and skills they need to design their shelter from a more knowledgeable perspective. The four KSBs are:

- Knowledge and Skill Builder 1: Surface Area and Volume Calculations
- Knowledge and Skill Builder 2: Conductive Heat Flow
- Knowledge and Skill Builder 3: Relationship between k Value and R Value
- Knowledge and Skill Builder 4: Structural Design

DESIGN ACTIVITY: *Once students complete the KSBs, they will form teams and will apply their knowledge and skill to the design of survival shelter.*

1. THE TEAMS WILL COLLABORATIVELY APPLY THEIR KNOWLEDGE AND SKILL TO THE SOLUTION OF THE GIVEN SHELTER DESIGN CHALLENGE BY:

a. Determining and defending their choice of shape of the shelter they propose to design;
b. Demonstrating that the shelter dimensions meet design specifications;
c. Calculating the surface area and volume of the shelter;
d. Calculating the minimum R value of the shelter wall and determining the appropriate materials to use to provide the necessary insulation;
e. Determining, through use of mathematical modeling, if their proposed shelter design will limit heat loss (in BTU/hour) to less than the heat generated by the body heat of the shelter inhabitants.

2. TEAMS WILL USE AN ITERATIVE *INFORMED DESIGN* PROCESS TO:

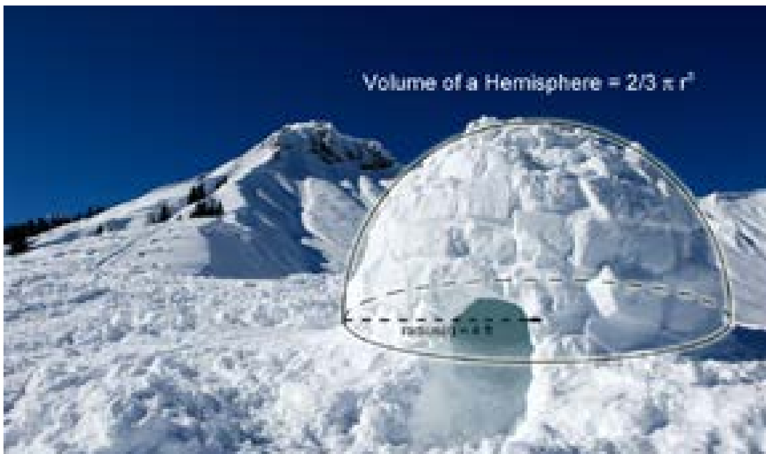
a. research and investigate a design challenge;
b. propose at least two alternative design solutions;
c. choose and justify their optimal solution; Select the optimal shapes and make tradeoffs
d. develop a prototypical model;
e. test and evaluate their prototype;
f. redesign their solution; and
g. communicate their achievements to an interested audience.

Information about the KSBs follows sequentially: KSBs 1-4.
Guidance for teachers relative to the design activity is presented after the KSB information.

KSB* 1

(*KNOWLEDGE AND SKILL BUILDER)

GEOMETRIC SHAPES



KSB1: SURFACE AREA AND VOLUME CALCULATIONS. KSB1 should take one period of class time

IN KSB 1, STUDENTS WILL LEARN THAT:
Volume is a measure of filling an object and surface area is a measure of wrapping an object.

TO DEMONSTRATE THEIR UNDERSTANDING, STUDENTS WILL:

1. Given representations of three dimensional (3D) shapes, students will compare and contrast volume and surface area.
2. Given the outside dimensions and the mathematical formulas for the volume of each shape, correctly calculate the volume of four geometric shapes: a cube, a sphere, a square-based pyramid, and a cylindrical prism.
3. Given the outside dimensions and the mathematical formulas for surface area for each shape, correctly calculate the surface area of four geometric shapes: a cube, a hemisphere, a square-based pyramid, and a cylindrical prism.
4. Given two dimensional nets reflecting a variety of geometric shapes, convert the nets to three dimensional models.

KSB 1 RELATIONSHIPS TO STANDARDS

NCTM GEOMETRY 6-8

- Precisely describe, classify, and understand relationships among types of two and three-dimensional objects using their defining properties.
- Use two-dimensional representations of three-dimensional objects to visualize and solve problems such as those involving surface area and volume (NETS and Stretchouts).

STANDARDS FOR TECHNOLOGICAL LITERACY (GRADES 6-8)

- **STL 9H**. Modeling, testing, evaluating, and modifying are used to transform ideas into practical solutions.
- **STL 11J**. Make two-dimensional and three-dimensional representations of the designed solution. These models can be graphical, physical, or mathematical (NETS and Stretchouts).

NAEP TECHNOLOGY AND ENGINEERING BENCHMARKS

- **T.8.5**. Some technological decisions involve trade-offs

WHY DO THIS KSB?

The reason students are going to be asked to calculate surface area and volume is that their shelter will have to be large enough to accommodate four people who must sleep side-by side within it and be able to sit up. They need to measure the body dimensions of the four team members to determine the minimum shelter envelope they need to sit up and lie down.

NOTES: 144 ft^3 is a good minimum volume based on height = 3 ft; width = 8 ft; depth = 6 ft. This is an approximation of the space needs of four people. The students should be able to find this volume easily using the formula V = l*w*h. The students may want to design a larger space to give them more room to move around and a place to store provisions.

SETTING THE CONTEXT

Ask students which shape their shelter should be. Invite a variety of answers such as cubes, hemispheres, and pyramids. Ask students why one shape is preferred over another.

Because the students are designing a shelter to keep them warm, they must be concerned with minimizing the surface area of the shelter, since heat flows through surfaces.

Since heat flows from warmer areas to cooler areas, heat inside a shelter will flow outward through the surfaces of the structure's walls. If a designer wishes to conserve heat within a structure, minimizing the area that is exposed to the cold will help the structure retain heat. Any inhabitants inside the shelter will therefore be kept warmer.
The shelter shape that would be the most efficient in terms of overall space would be a cube that would fit right over the envelope defined by the four students when they're sitting.

TEACHER SUPPORT:

Introduce the idea that shape matters*.* For a given volume, **a cube would not have the smallest surface area**. For example, a *cube* with a volume of 300 cubic feet (about 6.7 feet on a side) would have a surface area of 269 square feet. A hemisphere *with the same volume* (300 cubic feet) would have a surface area of 257.7 sq. ft.

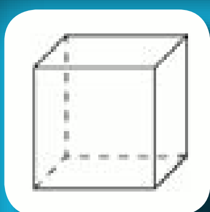
If we want to discount the portion of the shape that sits on the ground (since very little heat will be lost through the ground and most will be lost through the walls), the cube surface area (five sides) would be **224 square feet** and the hemisphere surface area will be **172 square feet**. So, for the same volume, the hemisphere will be a better heat retainer than the cube. Think about igloos!

TRADE-OFF - A KEY ENGINEERING CONCEPT

This is a good time to introduce the concept of trading off one desirable outcome in exchange for getting another desirable outcome, (with the result being a more optimal solution) and cubic shelters are much easier to build than hemispherical shapes. Students should discuss the trade-offs and what the optimal shape would be all things considered.

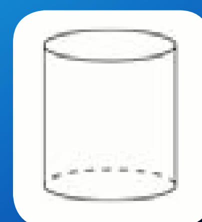
SURFACE AREA AND VOLUME

To calculate volume or surface area of a cube, sphere, square-based pyramid, and a cylindrical prism remind students of formulas that they have learned in their 8th grade math class.



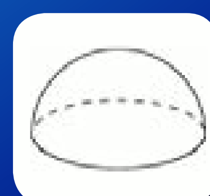
CUBE: Volume (V) of a cube is $V = s^3$
The surface area (SA) of a cube is $SA = 6*s^2$

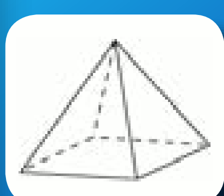
CYLINDER: Volume of a cylinder is $V = \pi r^2 h$
The surface area of a cylinder is $SA = 2\pi r^2 + 2\pi rh$



SPHERE: Volume of a sphere is $V= 4/3\ \pi r^3$
The surface area of a sphere is $SA = 4 \pi r^2$

HEMISPHERE: Volume of a hemisphere (half a sphere) is $V = 2/3\ \pi r^3$
The surface area of the hemisphere is: $SA_{hemisphere} = 2 \pi r^2 + \pi r^2 = 3 \pi r^2$



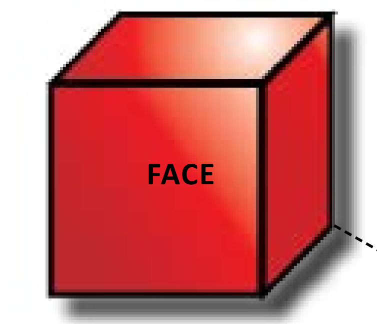


SQUARE-BASED PYRAMID: Volume of a square-based pyramid is $V = (1/3)\ l*w*h$
The surface area of the square-based pyramid is $SA = 2bh+ b^2$

MATHEMATICAL MODELING

FOR THOSE MATHY TYPES AMONG YOU, here is some more data that can explain these numbers. It's not entirely necessary to involve the students in all of the math so long as they develop a conceptual understanding that **shape matters** and that they understand that some shapes have more surface area than others for the same volume. For those students and teachers who want proof, here's the proof.

CONSIDER A CUBE FOR THE SHELTER



Since we know the volume, we can calculate the dimension of an edge (a side, s) using the formula for the volume of a cube. (A cube is a rectangular prism where all the edges are of equal lengths.)

The volume of a rectangular prism is V = lwh, or in the special case of a cube, $V=s^3$. Substituting the known volume for V, we get $300 = s^3$ and s = the cube root of 300. The cube root of 300 will be greater than 6 (6*6*6 = 216) and less than 7 (7*7*7 = 343). The cube root of 300 = is about 6.7. Therefore, the edge length of the cube with a volume of 300 cubic feet is 6.7 feet.

For a cube, the surface area is the area of all the faces. Since there are six faces and all the faces are squares and have equal areas, the SA= 6 times the area of any face. The area of one face is s^2. The surface area formula therefore, is $SA = 6*s^2$.

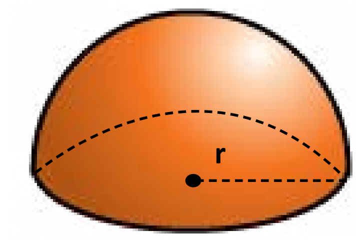
We can easily calculate the surface area of the cube by substituting the value for s into the SA formula.

ANSWER: $SA = 6*S^2$ OR $SA = 6 * (6.7)^2$ OR $6*6.7*6.7 = 269$ FT^2.
Without the base (since most heat is lost through the walls), the $SA = 5 * (6.7)^2 =$ **224.45** ft^2.

CONSIDER A SPHERE OR A HEMISPHERE FOR THE SHELTER

A hemisphere is half a sphere. When we calculate the volume of a hemisphere, we divide the volume of the sphere by 2. The volume of a sphere is $4/3\ \pi\ r^3$. The formula for the volume of a hemisphere therefore is half the volume of a sphere $(4/3\ \pi\ r^3) / 2)$ or $2/3\ \pi\ r^3$.

Since we know the volume of the hemisphere (300 cubic feet), we can use the formula for the volume of a hemisphere ($V = 2/3\ \pi\ r^3$) to solve for r, its radius.



Finding the radius. So, first let's find the radius of the hemisphere using the formula for its volume and solve for r. $(V_{hemisphere}) = 300 = 2/3\ \pi\ r^3$. Remember your algebra. To solve the equation, use the multiplicative property of equality and multiply each side by 3/2.

$$\mathbf{300\ (3/2) = (3/2)\ 2/3\ \pi\ r^3}$$

So,

$\pi\ r^3 = 300 * 3 /2$

$\pi\ r^3 = 900 / 2$

$\pi\ r^3 = 450$

$r^3 = 450 / \pi$ (Note: Use the value 3.14 for $\boldsymbol{\pi}$)

$r^3 = 143.3$

$r = \sqrt[3]{143.3}$

Or, the radius = just about 5.23 feet.

This is reasonable because we know 5*5*5 = 125 and 6*6*6 = 216.

We can also check this by substituting 5.23 for the radius in the volume formula and find the volume to be about 300 ft^3

Once we have found the radius, we easily find the SA of a hemisphere using the formula for the SA of a hemisphere. The formula for the SA of a hemisphere is also derived from the formula for the SA of a sphere. Remember that the formula for the SA of a sphere = $\mathbf{4\ \pi\ r^2}$ so you might be tempted to think that the SA of a hemisphere is simply half, that is **(4 π r2)/2 or 2π** $\mathbf{r^2}$.

(continued on next page.)

HOWEVER when we calculate the **area of the hemisphere**, we must remember to include the area of its circular base (πr^2). Therefore, the surface area of the hemisphere is:

$$\mathbf{SA_{hemisphere} = 2 \pi r^2 + \pi r^2 = 3 \pi r^2}$$

Just plug in the value for the radius that you found just before and solve.

So, we can use the formula SA = $3 \pi r^2$ to find the SA of the hemisphere.

SA = $3 \pi (5.23)^2$. SA = 3*3.14* 5.23*5.23 = 257.7 square feet.

If we want to neglect the base since there is very little heat lost through the base, just use the formula SA hemisphere = $2 \pi r^2$

$2 * \pi * r^2$ = 6.28 * 5.23 *5.23 = 171.77 square feet.

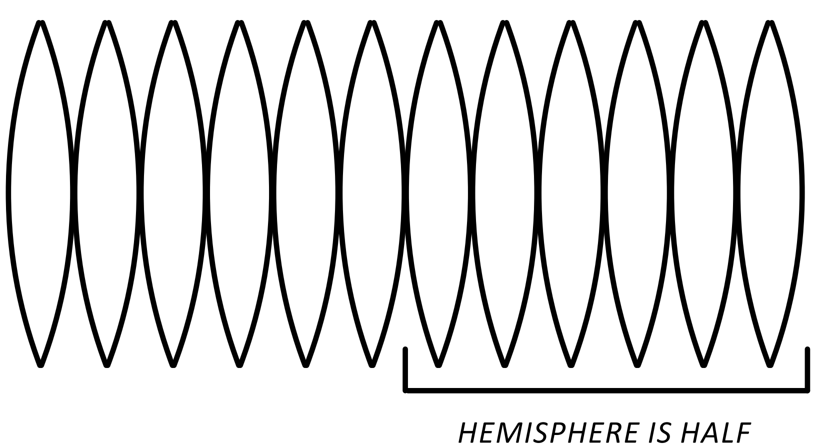
Compare this SA (171.77 ft^2) to the SA of the cube with the same volume (224.45 ft^2). You will see that the hemisphere would allow less heat flow than the cube.

NETS and STRETCHOUTS

In the KSB1 student guild there are five nets. Ask student to fold the nets. Before they fold the nets ask them to predict shapes. You may want them to measure sureface area and volume.

In the student guide, four nets are shown for four geometric shapes: A cube, a cylinder, a sphere, and a square-based pyramid. In engineering and technology, nets are often referred to as “stretchouts” or “development drawings.”

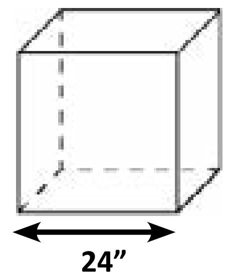
You might wish to make some paper models of each of the nets and demonstrate what they look like when stretched out, and how, when folded, reforms the 3D geometric shape. You might assign groups of students to each draw and fold one of the shapes and demonstrate what they’ve done to the class.



CHECK YOUR UNDERSTANDING - STUDENT GUIDE
KSB1 ANSWER KEY

If a cube has a side length of 24", figure out what the volume and the surface area are.

Write your answers below.
You can use a calculator.



V = ______________________ **SA =** _______________________

Activity found in KSB1 Student Guide ***page 6****.*

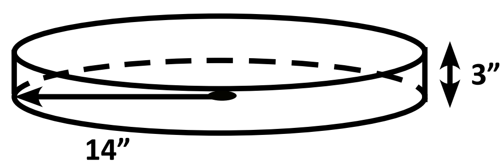
Activity found in KSB1 Student Guide ***page 8.***

If a cylinder has radius of 14" and a height of 3", figure out what the volume and the surface area are.

Write your answers to the right. You can use a calculator.

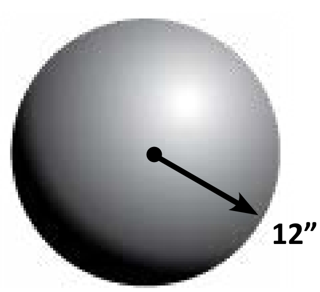
V = _____________________

SA = ___________________



If a sphere has a radius of 12", figure out what the volume and the surface area are.

Write your answers below.
You can use a calculator.



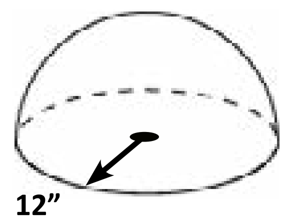
V = ______________________ **SA =** _______________________

Activity found in KSB1 Student Guide ***page 10.***

CHECK YOUR UNDERSTANDING - STUDENT GUIDE
KSB1 ANSWER KEY

If a hemisphere has a radius of 12”, figure out what the volume is.

Write your answer below.
You can use a calculator.



V = ______________________

Activity found in KSB1 Student Guide ***page 12.***

Activity found in KSB1 Student Guide ***page 12.***

If a hemisphere has a radius of 12” (same as above) figure out what the surface area is.

Write your answer below. You can use a calculator.

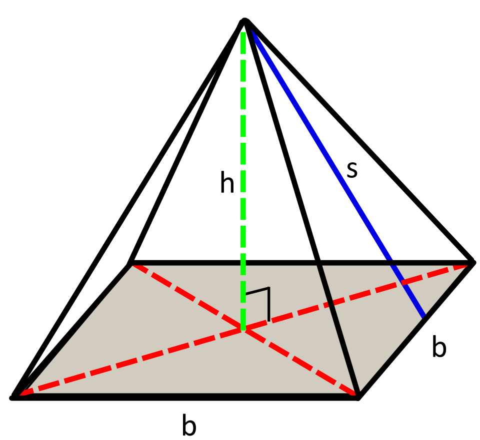
SA = ______________________

If a square-based pyramid has a height of 24”, a base side of 24”, and a slant height of 26.83”, figure out what the volume and the surface area are.

Write your answers below.
You can use a calculator.

V = ______________________

SA = ______________________

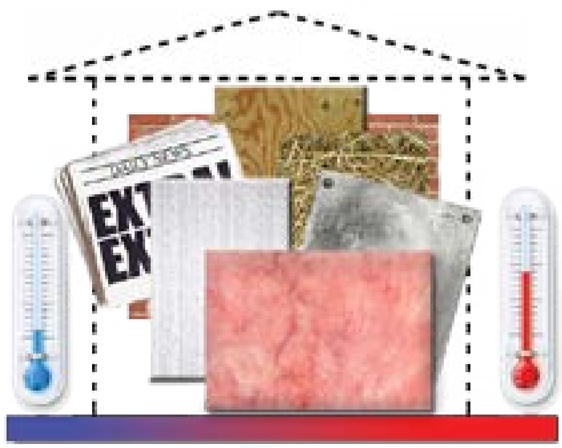


Activity found in KSB1 Student Guide ***page 14.***

KSB* 2

(*KNOWLEDGE AND SKILL BUILDER)

CONDUCTIVE HEAT FLOW



KSB 2: CONDUCTIVE HEAT FLOW. This should take three periods of class time.

IN KSB 2A, STUDENTS WILL LEARN THAT:
Heat (q) flows from hot (T_h) to cold (T_c) through a material by conduction.

TO DEMONSTRATE THEIR UNDERSTANDING, STUDENTS WILL:

Given an object with a temperature difference from one side to the other, students will describe that as the temperature difference (ΔT) increases, the conductive heat flow (q) increases.

IN KSB 2B, STUDENTS WILL LEARN THAT:
Since heat is transferred from a hot temperature (T_h) to a cold temperature (T_c) through a flat surface, reducing the amount of surface area reduces heat transfer.

TO DEMONSTRATE THEIR UNDERSTANDING, STUDENTS WILL:

Given objects with different surface areas (everything else being equal) the student will analyze how surface area affects conductive heat flow.

IN KSB 2C, STUDENTS WILL LEARN THAT:
Different materials conduct heat at different rates depending upon their thermal conductivity. Thermal conductivity is symbolized by the letter (k).

TO DEMONSTRATE THEIR UNDERSTANDING, STUDENTS WILL:

A. Given a list of materials with different k values, students will differentiate those that are good insulation materials from those that are not.

B. Given a heat source and two objects of the same dimensions made from different materials, students will be able to describe how different materials affect conductive heat flow.

IN KSB 2D, STUDENTS WILL LEARN THAT:
As the thickness of a material increases, the heat flow through it decreases.

TO DEMONSTRATE THEIR UNDERSTANDING, STUDENTS WILL:

Given different thicknesses of the same material (everything else being equal) students will analyze how thickness affects conductive heat flow.

IN KSB 2E, STUDENTS WILL LEARN THAT:
The formula that relates heat flow (q) to its determining factors is $q = kA (T_h - T_c)/L$

TO DEMONSTRATE THEIR UNDERSTANDING, STUDENTS WILL:

Given the heat flow formula and a standard calculator, students will correctly formulate an outcome based upon manipulation of the variables in the formula.

KSB 2 RELATIONSHIPS TO STANDARDS

NSES CONTENT STANDARD B.

- Students should begin become familiar with the idea that energy is an important property of substances and that most change involves energy transfer (KSB 2 A-E).
- Heat can move from one object to another by conduction (KSB 2A, E).
- Heat moves in predictable ways, flowing from warmer objects to cooler ones, until both reach the same temperature (KSB 2A).
- A substance has characteristic properties, all of which are independent of the amount of the sample (KSB 2C).

PROJECT 2061 BENCHMARKS FOR SCIENCE LITERACY

- **2061 4D/E6**. All materials have certain physical properties, such as strength, hardness, flexibility, durability, resistance to water and fire, and ease of conducting heat. (KSB2C).

NAEP BENCHMARKS

- **Table 3.1** Explain the properties of different materials that determine which is suitable to use for a given application or product (KSB 2C, KSB 2D).
- **D.8.4**: Simulate tests of various materials to determine which would be best to use for a given application (KSB 2C, KSB 2E,).

STANDARDS FOR TECHNOLOGICAL LITERACY (STL).

- **STL 16 H**: Much of the energy used in our environment is not used efficiently. Builders can conserve energy by installing better insulation (KSB 2C)

WHY DO THIS KSB?

This KSB will introduce students to the relationship between heat flow (Q) and the variables that affect it (temperature difference, ΔT; surface area, A; thermal conductivity, k; and thickness, L). Students will have to consider all these variables when they design a shelter to maintain heat. To determine whether they have chosen correctly, they calculate heat loss by using the heat flow formula **($Q = kA(T_h - T_c)/L$)** but each variable and its effect on heat flow is introduced separately in this KSB.

TEACHER SUPPORT:

WHEN YOU INTRODUCE THE KSB, explain that students will be using mathematics (mathematical models), just like engineers do, to predict how things will work. Stress that the math is all simple algebra, and should be prior knowledge for most eight graders and not beyond their capabilities. (If the algebra needs to be taught for the first time, you might enlist the help of a math teacher colleague.) There are five parts to KSB 2, parts 2A– 2E.

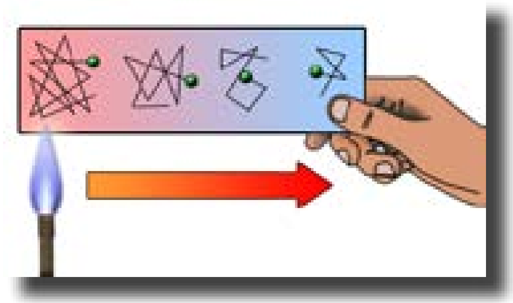
Rather than giving students the entire assignment all at once (which might be intimidating because of the mathematical formulas and calculations), hand out each part of the KSB separately.

IN KSB 2A, STUDENTS WILL LEARN THAT:

Heat (Q) flows from hot (T_h) to cold (T_c) through a material by conduction.
Begin this discussion by explaining that in order for their teams to design a shelter to limit the heat loss from the warm inside to the cold outside, they need to first be aware that heat flows from hot to cold through a material by **conduction.**

SETTING THE CONTEXT

Explain How Conduction Happens (the following is a simple explanation).



All matter is made up of atomic particles. Atomic particles all vibrate to some extent. Heat energy makes the particles vibrate faster. At the warmer side of an object, the particles vibrate more rapidly. These rapidly vibrating particles collide with other nearby particles and cause them to vibrate faster too. In this way, heat energy is transferred from warm areas to nearby cooler areas (which then also become warmer). The heat transfer continues until both sides are at the same temperature. Explain to the students that heat is measured in British Thermal Units (BTUs). One BTU is the amount of heat needed to raise the temperature of one pound of water by one degree Fahrenheit.

An animation that shows how heat flows from warm to cold can be seen at

http://www.phy.cuhk.edu.hk/contextual/heat/hea/condu/conduction_e.html

Discuss some examples of conductive heat flow that might be familiar to students, for example:

(1) When you use a stove to heat food in a metal pot, the bottom of the pot is in contact with the heat source. The atomic particles in the bottom of the pot begin to vibrate faster. Their increased energy is transferred to the neighboring atoms ultimately heating the inside of the pot. The heat energy from the inside of the pot is transferred, in a similar way, to the food that is being cooked, as the food too conducts heat (although not as well as the metal pot).

(2) When you hold a cup of hot liquid in your hand, you feel the heat that is transferred from the hot liquid to the cup, and then from the cup to your hand. Again, this occurs through the transfer of energy from warm areas to colder areas.

HEAT FLOW EXPERIMENT

EQUIPMENT:
- Aluminum rod
- Copper rod
- Glass rod
- Candle
- Stopwatch

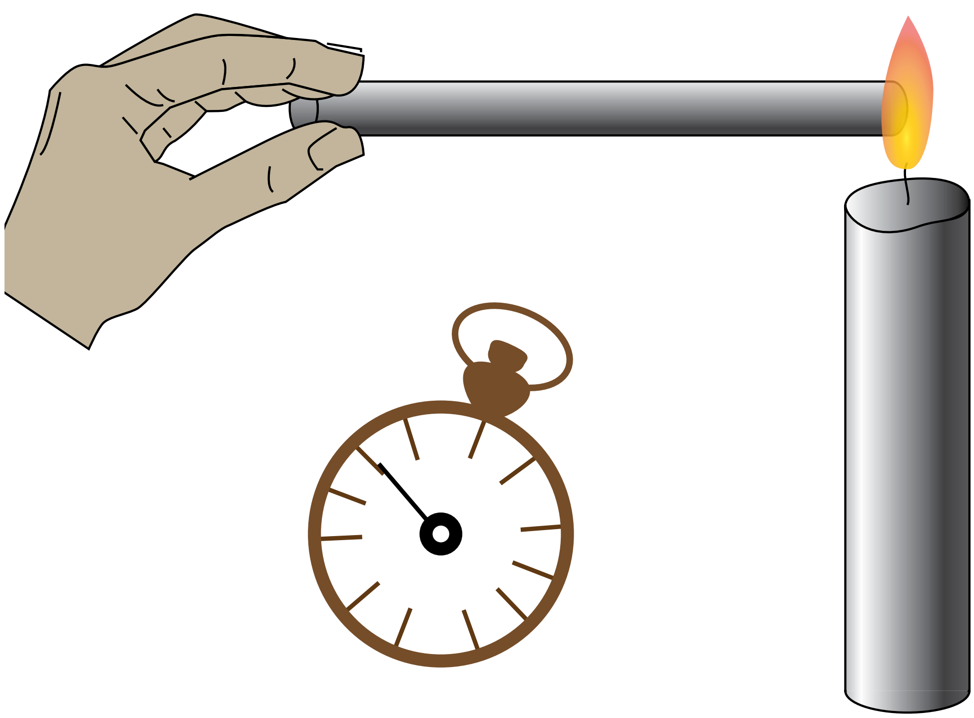
This experiment will show how heat flows from hot to cold.

PROCEDURE:

Light the candle. Take the aluminum rod, prepare to put it in the candle flame. Place one end of the rod into the flame, hold the other end with your hand, and start the stopwatch. When the rod gets warm, remove it from the flame, and note the time on the stopwatch. Carefully start at the warm end and feel the rod warmth slowly move your hand up the rod and note if it is hotter near the end that was in the flame.

WARNING: The rod may be very warm or hot in some area so be careful not to be burned.

Repeat the process for the copper and glass rods. Note the time differences. Note where the rods are hottest and coolest.



RELATE THESE EXAMPLES TO THE SHELTER DESIGN ACTIVITY.

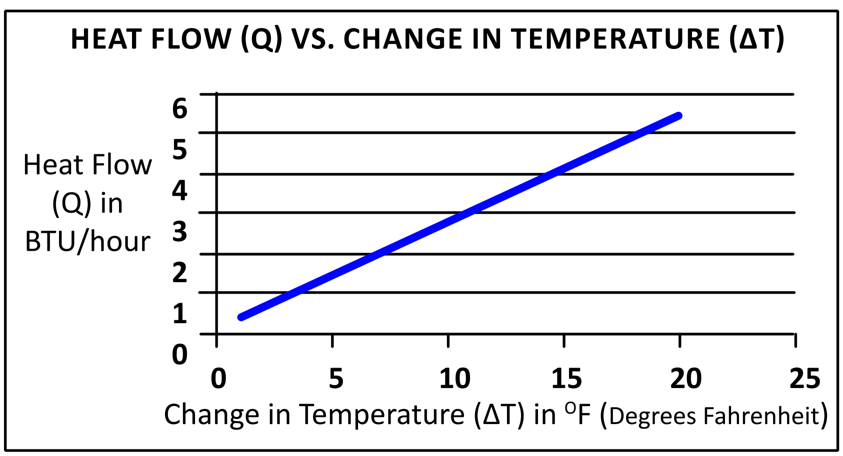
If heat is transferred from the inside of a shelter where it's warm, to the cold outside, it could get pretty uncomfortable for people in the shelter who want to stay warm. It's really important, therefore, to make sure that the shelter is designed to minimize the heat loss to the outside.

Explain that the difference between the hot inside temperature (T_h) and the cold outside temperature (T_c) is mathematically called *delta* T (ΔT). It simply means $T_h - T_c$. Ask the students to do a few examples (given some values of inside and outside temperatures) to demonstrate their understanding of **ΔT**, such as those shown below (taken from the student guide).

T_{HOT}	T_{COLD}	ΔT (T_h - T_c)
$T_h = 200^{\circ}$ F	**$T_c = 70^{\circ}$ F**	**$\Delta T = 130^{\circ}$ F**
$T_h = 100^{\circ}$ F	**$T_c = 60^{\circ}$ F**	**$\Delta T = 40^{\circ}$ F**
$T_h = 68^{\circ}$ F	**$T_c = 32^{\circ}$ F**	**$\Delta T = 36^{\circ}$ F**
$T_h = 60^{\circ}$ F	**$T_c = -10^{\circ}$ F**	**ΔT =** 70° F (Remember that subtracting a negative number means changing the sign and adding).

THE KEY CONCEPT FOR STUDENTS TO UNDERSTAND is that heat flow is directly proportional to ΔT ($Q \propto \Delta T$). You can show them this direct relationship using the graph below:

Explain that heat flow is *directly proportional* to the temperature difference between hot and cold areas. When ΔT is great, the rate of heat flow is faster. If ΔT is small, the rate of heat flow is slower. No matter what the rate, heat continues to flow from warm areas to cold areas until both areas are at the same temperature (reaches equilibrium).



(This graph actually models heat flow through a 1" thick piece of fiberglass that has a 1 ft x 1 ft cross sectional area).

Make sure that the students understand that as the temperature difference (ΔT) between hot and cold areas increases, the conductive heat flow through the material increases.

IN KSB 2B, STUDENTS WILL LEARN THAT:

Since heat is transferred from hot (T_h) to cold (T_c) through a flat surface area (like a wall) reducing the amount of surface area reduces heat transfer.

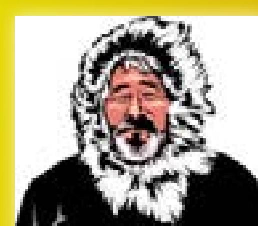
This part of the KSB teaches about the relationship between heat flow and the surface area of a structure.

SETTING THE CONTEXT

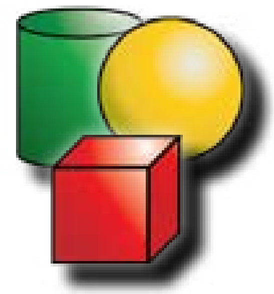
Ask the students to think about what happens when they go out into the cold. Body heat is transferred from the inner core to the outside air through the skin (the body's surface). Students must design their shelter to keep the heat from flowing from the warmth inside to the cold outside.

The rate of heat flow from the warm area inside the shelter to the cold areas outside has a lot to do with the surface area of the shelter. If the shelter has a large surface area, the rate of heat loss is faster. If the surface area is smaller, the rate of heat loss is slower.

You might like to discuss Allen's rule with the students. In 1877, Joel Allen observed that the length of arms and legs in warm-blooded animals relates to the temperature of their environment. Members of the same species (for example humans) who live in warm climates tend to have longer limbs than members of that species who live in colder climates. This rule, called Allen's rule, is based on heat flow. Longer limbs offer more surface area and lose heat more easily than shorter limbs which have less surface area and are more effective in maintaining heat. Ask the students why they think that the Inuit people, who live in cold northern climates, tend to have stockier bodies with shorter limbs than the Masai people who live in warm African climates and tend to have longer limbs and be taller?



REMEMBER, FROM KSB 1 THAT SHAPE MATTERS. Some shapes have more surface area than other shapes *even though they can contain the same volume*. In designing a shelter, students want to be able to house the four team members, but at the same time, *minimize the surface area* of the shelter.



THE KEY CONCEPT FOR STUDENTS TO UNDERSTAND is that heat flow is directly proportional to the surface area of a structure **($Q \alpha A$)**. That means if A goes up, Q goes up; if A goes down, Q goes down. If you want to minimize Q, design your shelter with the smallest surface area possible.

You may wish to discuss how heat sinks use the **$Q \alpha A$** relationship. A heat sink lowers the temperature of what it is attached to by increasing the surface area (usually using fins) which increases the rate of heat dissipation.

SURFACE AREA HEAT EXPERIMENT:

REQUIRED MATERIALS:

1) 9" x 5" Pyrex Loaf Pan (or equivalent)

http://www.pyrexware.com/index.asp?pageId=11&CatID=388&SubCatID=393&upc=400053000925

2) 15" x 10" Pyrex Baking Dish (or equivalent)

http://www.pyrexware.com/index.asp?pageId=11&CatID=388&SubCatID=393&upc=71160042933

3) Erasable Marker
4) Thermometer
5) Ruler or measuring tape
6) Timer

PROCEDURES:

1) Boil 3 quarts of water
2) Pour 1.5 quarts of water into each pan
3) Mark the height of the water on each pan
4) Measure the temperature of the water in each pan every 1 minute for 5 minutes
5) Measure the surface area of all sides of the pans in contact with the water (measure up to the level of the water that you marked in step 3)
6) Measure the surface area of the water that is exposed to the open air

WORKSHEET:

SURFACE AREA:

	9” x 5” Loaf Pan	15” x 10” Baking Dish
Long Sides		
Short Sides		
Base		
Top (open air)		
Total Surface Area		

TEMPERATURE READINGS:

	9” x 5” Loaf Pan	15” x 10” Baking Dish
Start		
1 minute		
2 minute		
3 minute		
4 minute		
5 minute		

OBSERVATIONS:

1) In which pan did the water cool faster? (circle one) Loaf Pan / Baking Dish

2) Based on this experiment, what observations can you make about the relationship between surface area and heat flow?

____

____

____

IN KSB 2C, STUDENTS WILL LEARN THAT:

Different materials conduct heat at different rates depending upon their thermal conductivity. Thermal conductivity is symbolized by the letter (k).
This part of the KSB teaches about the relationship between heat flow and the way materials conduct heat, based upon the material's atomic structure.

SETTING THE CONTEXT

Start off by asking students, from their own experience, to list some materials that conduct heat well (they may talk about metals because they know metal pots and pans conduct heat well). Then ask them to list some materials that do not conduct heat well (they may say wood, or plastic because they know that handles on pots and pans are made from these materials and don't feel hot to the touch). Note that materials that conduct heat well are good **conductors**, and materials that do not conduct heat well, are called **insulators**. Relate this to their past experience with electrical conductors and insulators. You can use this chart (from the student guide) if you like.

Material	Good Conductor	Bad Conductor	Example from Your Own Experience
Steel			
Aluminum			
Wood			
Plastic (e.g. Styrofoam ™)			
Air			
Ceramics (glass, clay)			
Paper			

Engage the students in a discussion about *thermal conductivity*. You might hold a variety of materials in a Bunsen burner flame for a consistent amount of time and (being careful not to allow any material to become too hot), invite the students to feel the temperature of each sample.

You can ask one student to be the time keeper, and another to feel the sample after the time is up. You can rotate student pairs to involve more students directly. Elicit from the students that *some materials (with higher k values) conduct heat better than other materials (with lower k values).*

Display the table of k values of some common materials (below). Ask students to rank a set of materials from high k values to low k values.

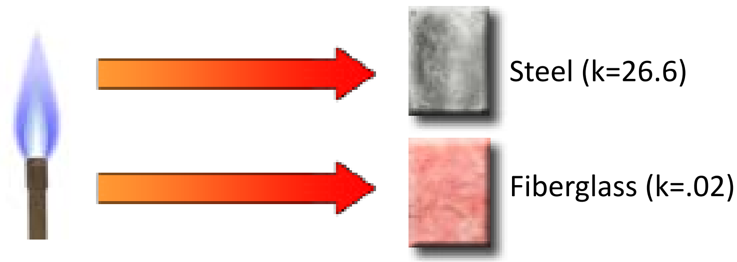
Discuss how air has a very low k value, and therefore is a very good heat insulator. Explain that other good insulators, like fiberglass and Styrofoam™, are filled with many air pockets which is a contributing reason to why they're such good insulators.

(Thermal Conductivities in BTU/hour-ft-deg F)			
MATERIAL	**k VALUE**	**MATERIAL**	**k VALUE**
Air	0.014	Paper	0.029
Aluminum	144.5	Polyethylene	0.24
Brass	62.99	Polystyrene (Styrofoam™)	0.017
Brick	0.39	Polyvinylchloride (PVC)	0.11
Cellulose (loose fill made from newspaper)	0.023	Rubber	0.09
Concrete	0.24	Silver	247.91
Cotton	0.017	Steel	26.6
Copper	236.9	Straw	0.052
Fiberglass	0.023	Urethane foam	0.012
Glass	0.61	Wood (balsa)	0.023
Gold	183.2	Wood (pine)	0.075
Hardboard	0.08	Wood (plywood)	0.075
Iron (cast)	31.78	Wood (oak)	0.098
Newspaper (cellulose)	0.023	Wool	0.04
Nylon	0.14	Zinc	67.04

THE KEY CONCEPT FOR STUDENTS TO UNDERSTAND is that heat flow is directly proportional to the thermal conductivity of a material **($Q \propto k$)**.

Ask the students to suggest which materials would best be used as insulation materials in construction. Explain that some insulation materials are self supporting, like plywood; and that others are only used as fill.

SHOW THE STUDENTS the diagram below, where two materials are being heated by the same heat source. Explain that the materials are exactly the same size, but one is made from steel, the other from fiberglass.



Using this example, ask the students to explain why and how the choice of one material or the other will affect conductive heat flow.

For a great example of how the high thermal conductivity of a material in a heat pipe is used to cool computer graphics cards, click on:

http://img.tomshardware.com/us/2006/07/24/graphics_beginners_guide/heatpipe.gif

(This example is included in the student materials.)

IN KSB 2D, STUDENTS WILL LEARN THAT:

Heat flow decreases with increasing thickness.
This part of the KSB teaches about the relationship between heat flow and the thickness of a material.

SETTING THE CONTEXT

Introduce the topic by asking the students to talk about the jackets they wear in cold weather. Elicit from them that in addition to the type of insulating material from which the jacket is made, the thickness also matters a great deal. In addition to using clothing as an example, you can discuss the thickness of insulation in sleeping bags, in homes, and in bedding.

THE KEY CONCEPT FOR STUDENTS TO UNDERSTAND is that heat flow and thickness are indirectly related ($Q \propto 1/L$). The thicker the material is, the less the heat flow through it. That means if *L* goes up, Q goes down; if *L* goes down, Q goes up. If the students want to minimize Q, they must design their shelter using thicker insulation materials.

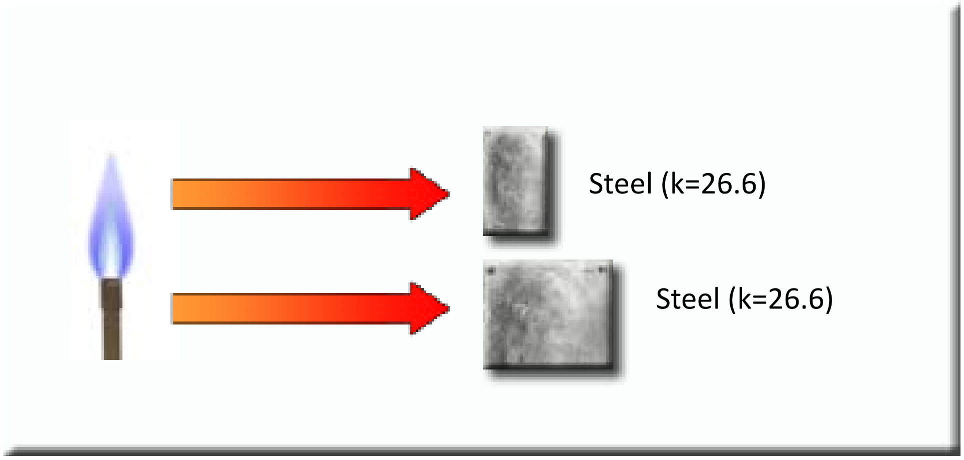
If the students need help in understanding what an indirect relationship is, use this example from the student guide.

REMEMBER WHAT YOU'VE LEARNED ABOUT FRACTIONS: if the numerator of a fraction stays the same but the denominator of that fraction gets larger, the value of the fraction decreases. If you have 1/2 a pizza, you have a lot more to eat than if you have 1/8 of a pizza. If the numerator stays the same, the amount you have to eat is *indirectly proportional* to the denominator of the fraction of the pizza that you have to eat. Look at these fractions:

1/2 1/3 1/4 1/5 1/6 1/7 1/8 1/9 1/10

You can see that as denominators get larger, the value of the fractions get smaller.
The relationship between heat flow and the thickness of a material is similar: they are also *indirectly related.* The greater the thickness of a material, the lower the amount of heat flow.

Direct the students' attention to the diagram below of two materials that are being heated by the same heat source. (This diagram is in the student guide.) The materials are made from the same material (in this case, steel). However, one is thicker than the other. Using this example, explain how the thickness of a material will affect conductive heat flow.



If you have access to a temperature probe and a computer, you can heat both samples and see how long it takes for each to reach a particular temperature. Because the thicker sample will limit heat flow, it will take longer for the thicker piece to heat up.

IN KSB 2E, STUDENTS WILL LEARN THAT:

The formula that relates heat flow (Q) to its determining factors is $Q = kA (\Delta T) / L$.

This part of the KSB teaches how to put together the relationships between heat flow and the individual variables (temperature difference, surface area, thermal conductivity of the material, and material thickness), into one formula.

Introduce this formula slowly. Begin by asking the students to tell you what kind a relationship there is between Q and k. They should say there is a direct relationship.

Then write $Q \propto k$ on the white board or chalk board.

Ask about the relationship between Q and surface area. Again, expect the response to be that there is a direct relationship.

Expand the expression now to read: $Q \propto k A$

Ask about the relationship between Q and ΔT. Once again, expect the response to be that there is a direct relationship.

Expand the expression again, so that it now reads: $Q \propto k A \Delta T$

Finally, ask about the relationship between Q and thickness (L). Expect the response to be that there is an indirect relationship.

Rewrite the expression as a formula: $\mathbf{Q = kA (\Delta T) / L}$

Change the proportionality sign to an equals sign because now, with the combination of variables, you can calculate heat flow exactly.

SAMPLE PROBLEM

Give the students a couple of problems where they have to find heat flow, given the other variables. In doing these problems, students should calculate the area of the structure without including the area of the side that touches the ground, since the majority of heat will be lost through the walls. You can use the example from the student guide, as follows:

EXAMPLE FROM STUDENT GUIDE: Figure out how much heat is lost through the walls of a cabin shaped like a cube. It is made from oak boards that are 2" thick with surfaces that measure 10 ft. x 10 ft. The inside temperature of the cabin is 68º F and the outside temperature is 15º F. (Remember to look up the k value for oak, and to convert the thickness to feet.) The answer you should get is 15,588 BTU/hour.

See the worked example that follows:

Givens

$\Delta T = 53^{o}$ F
k value for oak is 0.098
Thickness is 2", or 1/6 ft = 0.1666 ft.
Area of cubic shape is 5 S^2 =500 ft^2. (Note that we are disregarding the area of the bottom since compared to the walls, very little heat is lost through the ground which has infinite thickness.)

Use: **$Q = kA (\Delta T) / L$**
Q = 0.098 x 500 x 53 / 0.1666 = **15588 BTU/hour**

Discuss with the students that the heat generated by the bodies of the four survivors in the shelter would be about 1360 BTU/hour. (Each person generates about 100 watts, or 340 BTU/hour since 1 watt = 3.4 BTU/hour)

If the heat loss in the above example = 15588 Btu/hour, there is much more heat loss than there is heat gain (1360 BTU/hour), and the team members will freeze.

In this case, to design a shelter that would keep the survivors warm, either the k value must be reduced (since lower k values are better insulators), the surface area must be reduced, the temperature difference must be reduced, or the thickness must be increased. Some combination of these changes would be fine, so long as Q is calculated to be less than the available body heart, 1360 BTU/hour.

CHECK YOUR UNDERSTANDING - STUDENT GUIDE
KSB2 ANSWER KEY

Figure out **ΔT** for each set of temperatures in the table to the right. **Write in your answers.**

T_{HOT}	T_{COLD}	$\Delta T\ (T_H - T_C)$
$T_H = 200^o$ F	$T_C = 70^o$ F	
$T_H = 100^o$ F	$T_C = 60^o$ F	
$T_H = 68^o$ F	$T_C = 32^o$ F	
$T_H = 60^o$ F	$T_C = -10^o$ F	

*Activity found in KSB2 Student Guide **page 4**.*

In the space below, describe how surface area affects conductive heat flow.
Use a complete sentence to explain the relationship below.

____
____
____
____
____
____

*Activity found in KSB2 Student Guide **page 7**.*

CHECK YOUR UNDERSTANDING - STUDENT GUIDE
KSB2 ANSWER KEY

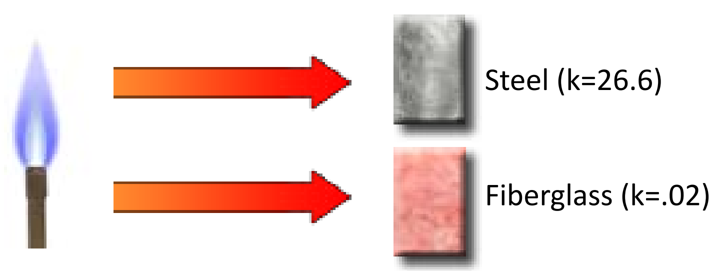
*Activity found in KSB2 Student Guide **page 8**.*

From your own experience, **put a check** next to the materials in this list that you think are good or poor conductors of heat. **Then give an example that justifies your decision.**

Material	Good Conductor	Bad Conductor	Example from Your Own Experience
Steel			
Aluminum			
Wood			
Plastic (e.g. Styrofoam ™)			
Air			
Ceramics (glass, clay)			
Paper			

*Activity found in KSB2 Student Guide **page 10**.*

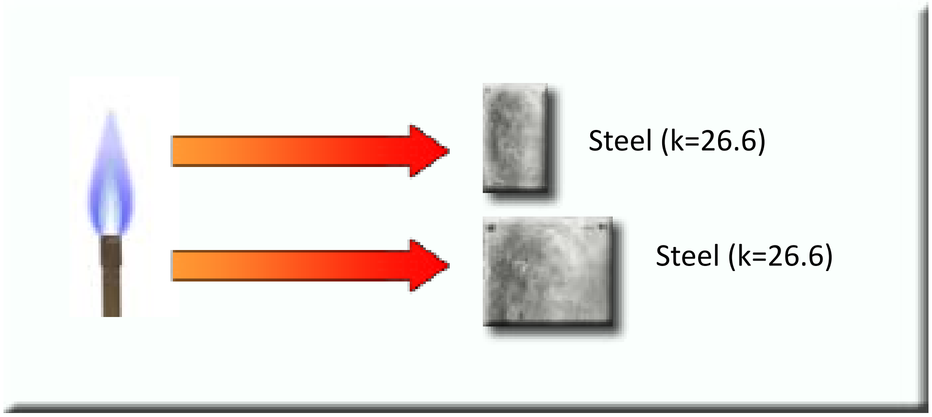
In the diagram to the right, two materials are being heated by the same heat source. The materials are exactly the same size, but one is made from steel, the other from fiberglass.
Using this example, explain (**using a complete sentence**) how the different materials will affect conductive heat flow.



CHECK YOUR UNDERSTANDING - STUDENT GUIDE
KSB2 ANSWER KEY

In the diagram below, two materials are being heated by the same heat source. The materials are made from the same material (in this case, steel). However, one is thicker than the other.

Using this example and **in the space below the diagram**, explain how the thickness of a material will affect conductive heat flow.



*Activity found in KSB2 Student Guide **page 13**.*

Your Turn! Figure out how much heat is lost through the walls of a cabin shaped like a cube. It is made from oak boards that are 2” thick with surfaces that measure 10 ft. x 10 ft. The inside temperature of the cabin is 68° F and the outside temperature is 15° F. (Remember to look up the k value for oak, and to convert the thickness to feet.) The answer you should get is **15,582 BTU/hour**.

SHOW YOUR WORK HERE

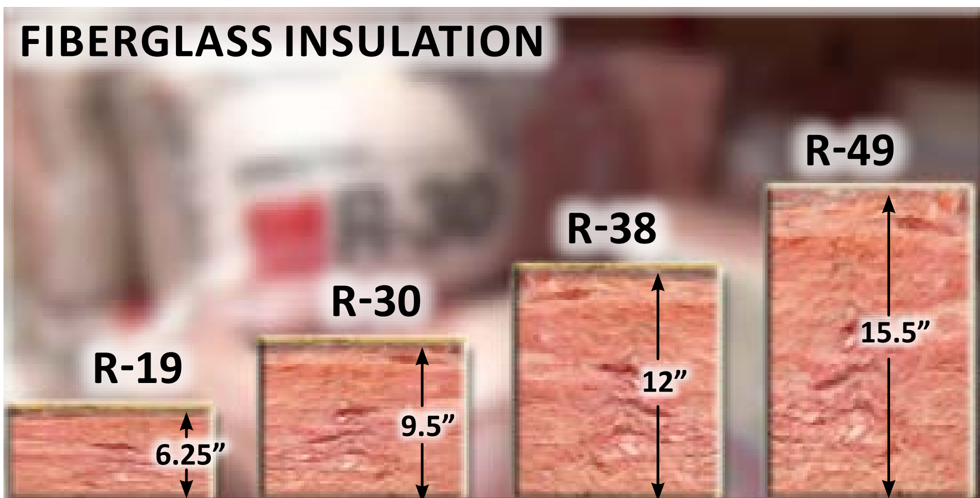
$(Q = kA (\Delta T) / L)$

*Activity found in KSB2 Student Guide **page 16**.*

KSB* 3

(*KNOWLEDGE AND SKILL BUILDER)

RELATIONSHIP BETWEEN K VALUE AND R VALUE



KSB 3 – RELATIONSHIP BETWEEN K VALUE AND R VALUE. This should take 2 periods of class time.

IN KSB 3, STUDENTS WILL LEARN THAT:

1. k value and R value are both measures of a material’s resistance to heat flow. k value relates only to the type of material where R value also takes into account the material’s thickness (L).

*2. Since R value takes thickness (L) into account, yet is related to k value, **R, L, and k can be expressed in a relationship**. The R value of a material equals its thickness / its k value (**R = L/k**).*

3. The total R value (R_t) of a system of materials is the sum of each of the individual R values (Rt = R1 + R2 + R3 + R....).

TO DEMONSTRATE THEIR UNDERSTANDING, STUDENTS WILL:

1. *Given information about k value and R value, students will describe the similarities and differences between them. (Q. 19-25)*

2. *Given information about the relationship between k value, R value, and thickness of a material, students will analyze a variety of materials to determine differences in k and R value. (Q.26)*

3. *Given k values and thicknesses for several different materials, students will calculate the R value of each material using the formula $R = L/k$. (Q. 27-31)*

4. *Solve for heat loss using the formula $Q = A\,(\Delta T) / R$ given surface area, R value, and ΔT. (Q.33)*

5. *Given individual R values of several materials, students will determine the total R value of a system made from layers of those materials by summing the individual R values*

KSB 3 RELATIONSHIPS TO STANDARDS

NSES CONTENT STANDARD B.

- A substance has characteristic properties, all of which are independent of the amount of the sample.

NAEP BENCHMARKS

- **D.8.4:** Simulate tests of various materials to determine which would be best to use for a given application.

STANDARDS FOR TECHNOLOGICAL LITERACY (STL).

- **STL 16 H:** Much of the energy used in our environment is not used efficiently. Builders can conserve energy by installing better insulation.

WHY DO THIS KSB?

Both k and R values are measures of how a material conducts (or retards) heat flow. Doing calculations using R values rather than using k values makes sense since insulation materials are sold in stores according to their R values. As students will learn shortly, There is a relationship between k value and R value **(R = L/k)** that allows us to simplify the heat flow formula and use one variable (R), instead of two variables (L and K).

There is a very good discussion of heat flow at this URL:

http://en.wikipedia.org/wiki/R-value_(insulation)

An excellent and simple discussion of k value and R value can be found at this URL:

http://www.nomacoinsulation.com/pdf/TS12_0108.pdf

SETTING THE CONTEXT

Show the students a sampling of store-bought insulation and explain that the insulating values are expressed as R values.

Examples of k and R values for some common materials are seen in the table below:

Material	Thermal Conductivity SI Units	Thermal Conductivity English Units	R-value (L/k) English Units	Description of material thickness
	(W/m·K) AT 25º C	Btu/(ft hr ºF) or [W/m·K * 0.5779]	L in feet k in Btu/(ft hr ºF)	
Air	0.024	0.0138696	6.008344389	For a 1” air space
Aluminum	250	144.5	0.0005767	1” thick
Brick	0.69	0.398751	0.626957675	For a 4” thick brick
Concrete	0.42	0.242718	0.343333965	For one inch of concrete
Cotton	0.03	0.017337	4.806675511	For one inch of cotton
Copper	410	236.939	0.000044	For 1/8 " copper sheet
Fiberglass	0.04	0.023116	3.605006633	For a 1" thick batt
Glass	1.05	0.606795	0.017166698	For a 1/8" sheet
Newspaper (crumpled cellulose)	0.04	0.023116	0.009012517	For a single sheet of newsprint (.0025 in.)
Nylon	0.25	0.144475	0.001442003	For a material thickness of 0.0025 in.
Paper	0.05	0.028895	0.011536021	For a single sheet of 20 lb copy paper
Polyethylene	0.42	0.242718	0.002060004	For a six mil sheet (0.006 inches)
Polypropylene	0.1-0.22	0.0578 TO 0.127	0.005411548	For a six mil sheet (0.006 inches)
Styrofoam™ (sheet)	0.03	0.017337	4.806675511	For a one-inch thick piece
Silicon	148	85.5292	0.000243582	For 1/4" of silicon
Wood (balsa)	0.04	0.023116	0.450625829	For a 1/8" thick sheet
Wood (pine)	0.13	0.075127	0.554616405	For a 1/2" board
Wood (plywood)	0.13	0.075127	0.554616405	For a 1/2" board
Wood (oak)	0.17	0.098243	0.424118427	For a 1/2" board
Wool	0.07	0.040453	0.010300019	For a piece 0.005" thick

Ask the students to find the R value if they know the k value and the thickness. From the student materials, here are some examples (Answers are included):

Material	Thickness in inches	Thickness in feet (L)	k value	Calulate R value (use L/k)
Aluminum	1/4”	0.25/12 = 0.02	144.5	0.000144S
Brick	4”	4/12 = 0.333	0.41	0.81
Fiberglass Batt	3.5”	3.5/12 = 0.29	0.019	15.2
Stone	4”	4/12 = 0.333	1.04	0.32
Plywood	1”	1/12 = 0.0833	0.075	1.11

REMEMBER TO STRESS THAT L, THICKNESS, IS IN FEET, NOT INCHES!
One inch = 1/12 foot or 0.08333 feet.

TEACHER SUPPORT

Help the students understand how substituting R for L and K in the heat flow formula simplifies their calculations significantly.

Now using the relationship between R, L, and k, watch what happens to our heat flow formula.
We start with the original heat flow formula:

$$Q = k\,A\,(\Delta T)\,/\,L$$

Do you see that we have a k/L term in our heat flow formula? Remember that **R = L/k**; therefore, 1/R = k/L (invert both terms).

Since 1/R = k/L, just substitute 1/R for k/L and now our formula becomes simpler:

$$Q = \frac{k\,A\,(\Delta T)}{L} = \frac{1\,A\,(\Delta T)}{R}$$

Now, Q simply becomes Q = A (ΔT) / R

Not only do we have one less variable to deal with, but we can use R values, which typically are larger numbers as opposed to k values which are fractions (or expressed as smaller decimals).

From the student guide, help students recalculate the problem from KSB 2E, using R value.

Using the formula from the previous page, redo the problem you did in KSB 2E, using R instead of k and L. That is, find the number of Btu/hour that will be necessary to maintain an inside temperature of 70º F if the outside temperature is 25º F. Assume a cubic structure 6' on each side (remember, we only are considering five sides, not the bottom) and that the structure is made of plywood that is 1" thick.

(You figured out the R value for 1" thick plywood a moment ago in your sample R value calculations. You probably found that plywood that is 1" thick has an R value of 1.1106). Using R is easier than using k and L:

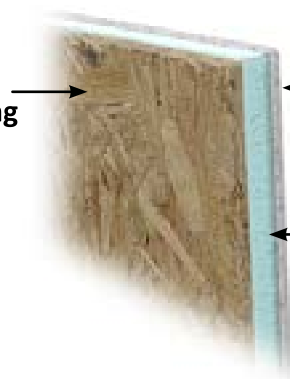
$$Q = A\ (\Delta T) / R$$
$$Q = 5*6*6\ (45) / 1.1106$$
$$Q = 7293 \text{ BTU/hour.}$$

The next important concept to teach in this KSB is that when you layer materials in a "sandwich," the R values add.

From the student guide:

Math at Work: Heat flow through a wall

In this diagram of a wall section, the total R value of the wall would be the R values of the exterior sheathing, the foam core insulation, and the interior sheathing all added together. If the exterior sheathing is made from ½" plywood (R=0.55), the core is made from 1" of Styrofoam™ (R=4.8), and the interior sheathing is made from hardboard (masonite) (R=0.24), the total R value of the wall system would be: 0.55 + 4.8 + 0.24 =5.59.



In using the heat flow formula to calculate heat flow through the wall ($Q = A\ (\Delta T) / R$), you'd use 5.59 as the value for R in the denominator.

Explain to the students that if they took two pieces of fiberglass insulation that were each 3.5 inches thick and placed one on top of the other, the R value would double. However, if they squeezed one piece so that it was thinner, the R value of the combination would increase, but it would NOT double since they've squeezed air (an excellent insulator) out of the combination.

CHECK YOUR UNDERSTANDING - STUDENT GUIDE
KSB3 ANSWER KEY

*Activity found in KSB3 Student Guide **page 4**.*

Let's do some simple calculations:
If you know the k value of a material and you know its thickness, let's find the R value. Calculate the follow R valves below.

Write your answer in the far right column.

R=L/k (and don't forget that L, thickness, is in feet, not inches).
One inch = 1/12 foot or 0.08333 feet.

Material	Thickness in inches	Thickness in feet (L)	k value	Calulate R value (use L/k)
Aluminum	1/4"	0.25/12 = 0.02	144.5	
Brick	4"	4/12 = 0.333	0.41	
Fiberglass Batt	3.5"	3.5/12 = 0.29	0.019	
Stone	4"	4/12 = 0.333	1.04	
Plywood	1"	1/12 = 0.0833	0.075	

*Activity found in KSB3 Student Guide **page 5**.*

Figure out the R_t (Total R Value) of the following combinations of materials.
Write your answer in the far right column.

Material 1	R1	Material 2	R2	Material 3	R3	Total R Value
1" Polyurethane Foam	6.9	1" Styrofoam™	4.8	1" Cork	2.08	
1/16" Cardboard	0.64	1" Polyethylene Foam	4.38	1" Straw	1.6	
1" Cork	2.08	1/16" Cardboard	0.64	1" Styrofoam™	4.8	

CHECK YOUR UNDERSTANDING - STUDENT GUIDE
KSB3 ANSWER KEY

Answer the follow questions.

1. Of the materials used above which has the highest R value?

   ____

2. Of those same materials, which has the highest k value?

   ____

(Check one) **YES** **NO**

3. Would ½" thick aluminum have the same R value as ¼" thick aluminum? ☐ ☐

4. Would ½" thick aluminum have the same k value as ¼" thick aluminum? ☐ ☐

*Activity found in KSB3 Student Guide **page 6**.*

KSB* 4
(*KNOWLEDGE AND SKILL BUILDER)
STRUCTURAL DESIGN

KSB 4 – STRUCTURAL DESIGN. This should take 5 periods of class time.

IN THIS KSB, STUDENTS WILL LEARN THAT:

KSB 4A: *Dead loads, live loads, and wind loads are among those that have to be taken into consideration when designing a structure (**one period of class time**).*

TO DEMONSTRATE THEIR UNDERSTANDING, STUDENTS WILL:

1. Given information about dead and live loads, students will define dead load as a load of constant magnitude (such as the weights of the materials of construction) and live load as a load that changes in magnitude and/or location (such as people in a building, or cars on a bridge).

2. Given a representation of wind blowing against a tower on a foundation that supports a platform with a filled water tank upon it, students will correctly label dead loads and live loads.

3. After engaging in an activity that shows the effect of wind on a structure (such as playing a game that illustrates how wind affects a structural shape, or seeing a video of "Galloping Gertie," the Tacoma Narrows Bridge Collapse), students will recognize that wind loads have to be considered in designing a structure in addition to "dead loads" and "live loads."

KSB 4B: *Structural integrity refers to the ability of individual structural members that comprise the structure (and their connections) to perform their functions under loads (**one period of class time**).*

TO DEMONSTRATE THEIR UNDERSTANDING, STUDENTS WILL:

1. Given a representation of a structure that supports a load, students will recognize that a lack of structural integrity would affect the structure's ability to stand up under load.

KSB 4C: *Selecting materials involves making tradeoffs between qualities (**one-half period of class time**).*

TO DEMONSTRATE THEIR UNDERSTANDING, STUDENTS WILL:

1. After explaining that structural integrity depends upon the ability of individual structural members that comprise the structure to perform their functions under loads, students will explain how selecting materials for a structural project involves making tradeoffs between competing qualities such as its strength, cost, availability, and the ease of working with the material.

KSB 4D: *The overall stability of a structure and its foundation refers to its ability to resist overturning (toppling over) and lateral movement (sliding) under load (**two periods of class time**).*

TO DEMONSTRATE THEIR UNDERSTANDING, STUDENTS WILL:

1. Given the challenge to improve the structural stability of a structure students will select improvements that will help the structure resist overturning and lateral movement under load. (Q. 45). See reworded test item as well.

2. After investigating the shape of 3 D structures, students will evaluate the wind load effect on these shapes. (Q.44)

KSB 4E: *Structural design is influenced by function, appearance, cost, and climate/location (**one half period of class time**).*

TO DEMONSTRATE THEIR UNDERSTANDING, STUDENTS WILL:

After reviewing images or models of a variety of structures built for different purposes in different geographic areas (deserts, mountains, icy climates) students will describe how structural design is influenced by function, appearance, cost, and climate/location.

KSB 4 RELATIONSHIPS TO STANDARDS

STANDARDS FOR TECHNOLOGICAL LITERACY (STL).

- **STL 2 A**. Making tradeoffs is a decision process recognizing the need for careful compromises among competing factors.
- **STL 20 F**: The selection of designs for structures is based on factors such as function, appearance, cost, and climate/location.
- **STL 20 G**: Structures rest on a foundation.

NAEP TECHNOLOGICAL AND ENGINEERING BENCHMARKS

- **T.8.5**. Some technological decisions involve trade-offs between environmental and economic needs, while others have positive effects for both the economy and environment.

NEW NRC SCIENCE STANDARDS (DRAFT, AUGUST 2010)

- **ET2. C**. Optimizing and Making Tradeoffs: Finding the best solution is an iterative process involving decisions concerning tradeoffs among competing criteria, and multiple tests and improvements.

Students will need the following materials and equipment to do this KSB:

- Access to the Internet
- About 30 drinking straws, ¼” diameter, about 10-12” long
- A block of modeling clay about 8” long x 8” wide x 4” high.
- Hot glue gun and glue sticks
- Safety goggles
- A square of corrugated cardboard, about 6” on a side
- An powerful electric fan

SAFETY NOTES:

Students are going to be working with a hot glue gun and hot glue. ***Hot glue when used doesn’t look hot, but it is.*** Make sure students understand that they need to be really careful. *They must not touch the hot glue or the glue gun once it gets hot.*

Be sure that students wear safety goggles whenever they are working with hot materials.

WHY DO THIS KSB?

The purpose of this KSB is to provide students with the background necessary to design a structure and introduce some important concepts necessary to structural design. The KSB invites students to design a water tower as a means of introducing these key concepts. The ideas students learn in designing the water tower will provide them with background they need to design their survival shelter so that it too, stands up under load.

SETTING THE CONTEXT

Introduce students to the evolution of structures from temporary to permanent dwellings. Discuss how people who live semi-nomadic lives like the Bedouins still use simple structures. Point out the photographs in the student guide of simple structures, early structures build by the Romans (such as the Roman Colosseum), and remind the students that all structures, including the one they will build, are designed to serve a particular purpose. In this case, the structure must keep team members safe and reasonably comfortable until a rescue team reaches them. You can direct the students to some simple shelter designs at the following URL:

http://www.solareagle.com/PREP/SHELTER.HTM

TEACHER SUPPORT

KSB 4A. Dead loads and live loads are among those that have to be taken into consideration when designing a structure.

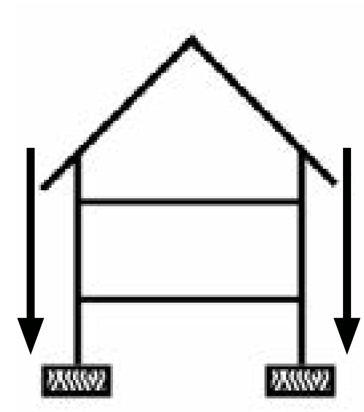
Explain the difference between dead loads and live loads.
The **dead load** is the weight of the structure itself and permanent fixtures.

Dead loads are loads which are always fixed in position, and of unchanging magnitude.

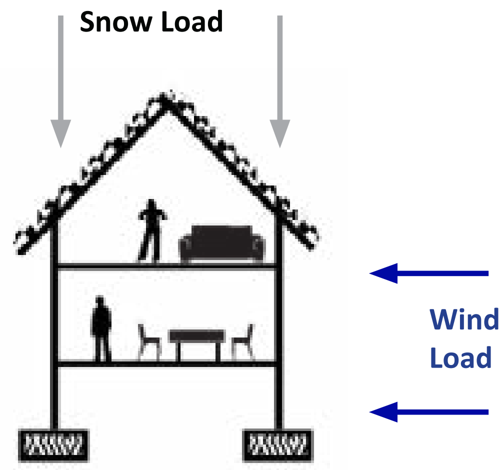
Live loads are loads that that are temporary or moving and can vary in magnitude. Some live loads move (cars, trucks, trains, etc.) and some are moveable (goods, furniture, file cabinets, etc.).

Wind and snow loads are a special case of live loads, but since they can create other effects (for example, wind can create a vacuum effect on a roof), engineers consider them separately.

When students design their shelter, they must design it so that it stands up under dead load and any live load.



DEAD LOAD



LIVE LOADS

CHECK YOUR UNDERSTANDING:

Define dead load and give some examples. Explain why dead load needs to be considered in structural design.

ANSWER: Dead loads are loads which are always fixed in position, and of unchanging magnitude. Dead loads always act vertically.

Define live load and give some examples. Explain why live load needs to be considered in structural design.

ANSWER: Live loads are loads that that are temporary or moving and can vary in magnitude. Examples would be goods stored on a floor; furniture, file cabinets, or moveable objects in an office; people in a building; cars or trains on a bridge.

Discuss some examples of disasters that occurred because errors were made in calculating dead loads and live loads. See the following links relative to dead load disasters:

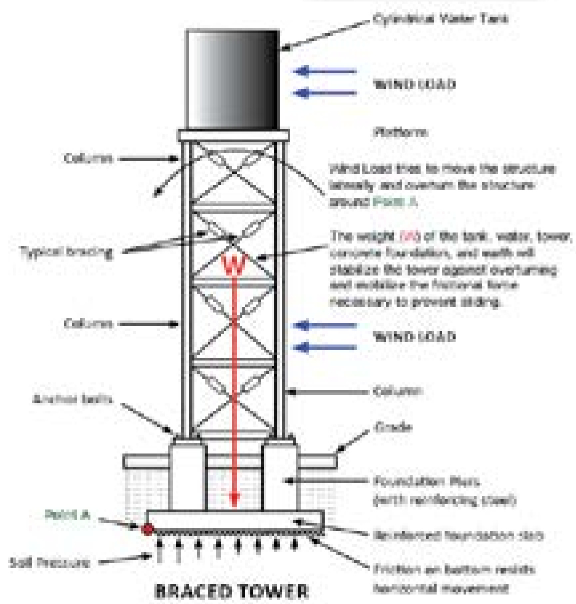
- http://en.wikipedia.org/wiki/Hotel_New_World_disaster
- http://www.911myths.com/html/progressive_collapse.html
- http://covertoperations.blogspot.com/2009_05_01_archive.html

See the following link relative to dead load disasters:
- http://en.wikipedia.org/wiki/Hyatt_Regency_walkway_collapse

See the following link relative to wind load disasters:
- http://en.wikipedia.org/wiki/Tacoma_Narrows_Bridge_(1940)

and see the amazing video of the collapse at:
- http://www.youtube.com/watch?v=HxTZ446tbzE

Have the students look at the drawing of the water tower in the student guide and ask them to form small groups and identify dead loads, live loads, and wind loads.



Have each student in the group fill in the following table.

Specify whether each of the following loads is a dead load or a live load by putting a check in the appropriate box.		
Load	**Dead Load**	**Live Load**
Water tank itself	✓	
The tower itself	✓	
Wind		✓
Water sloshing around in the tank		✓

KSB 4B: Structural integrity refers to the ability of individual structural members that comprise the structure (and their connections) to perform their functions under loads.

The important point to clarify is that **structural integrity** relates to how well the structural members that make up the structure, and their joints, **can perform their functions under load.**

Have the students make some predictions.

Water weighs about 8.33 pounds per gallon. If the water tank on top of the tower shown below holds 500 gallons of water, the weight of the water in the tank = 8.33 x 500 or about 4165 pounds. When the tank is filled, this tower has to support a substantial dead load.

What effect do you think that bracing the columns horizontally would have?

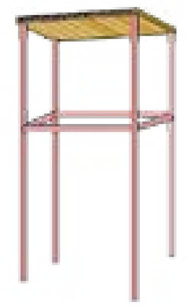
Answer: The columns would resist buckling and the structure would be able to support a greater load.

What do you think would happen to the vertical columns if the water tank was filled with 500 gallons of water and the tower columns were very thin?

Answer: The columns would buckle and collapse.

Now lead the students through an activity where they build a model and test their predictions. See the student guide for details. It is suggested that the model be build with drinking straws and a platform be made from corrugated cardboard. You can substitute any materials you like, but the idea will be to first build a model without any bracing, then in stages, make the columns out of a heavier material, and then add horizontal bracing. Elicit from the students how each change affected the tower's ability to support weight.

KSB 4C: Selecting materials involves making tradeoffs between qualities



Discuss tradeoffs students might have made in designing their tower. Explain that a tradeoff is giving up one thing to get something else, normally an improvement. In making improvements to the tower, ask students what tradeoffs they would have had to make.

Possible answers: if they used a metal platform instead of cardboard platform, they would gain strength, at the expense of higher cost and a greater weight (dead load). The same is true if they used metal columns instead of straws (they would have gained strength, at the expense of higher cost and greater weight).

KSB 4D: The overall stability of a structure and its foundation refers to its ability to resist overturning and lateral (sideways) movement under load.

The focus of this part of the KSB is to see the effect of wind load on a structure, and to make sure that the structure is designed to have enough stability to resist the effects of the wind.

Be sure that the students understand that STABILITY refers to a structure's ability to **resist overturning and lateral (sideways) movement under load.**

A. Find a powerful fan that will blow enough wind to move the simple structure (only horizontal bracing with no foundation) laterally and cause the structure to overturn. You may have to use a blower with a squirrel cage motor to generate enough cubic feet per minute of air to act convincingly upon the structure.

Ask the students to explain what they noticed, in response to the following question:

Under wind load, does the tower stand up or does it try to overturn? Explain what you see.

ANSWER: Without a foundation, the tower moves laterally (sideways).

Discuss the Leaning Tower oF Pisa in Italy that was built in 1173. The reason that the tower leans is that soil the foundation was not strong enough to hold the weight of the tower and the condition became worse under wind loading.

The tower is built on layers of sand and clay. Engineers calculate that the pressure was 20 pounds/square foot - unheard of for soil. When the wind blows, the pressure increases even more.

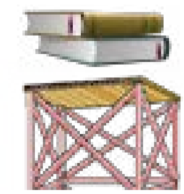
http://funphysics.jpl.nasa.gov/story/leu-demo.html

B. Now have the students attach the tower to a foundation made from a block of modeling clay. The foundation will provide additional stability and the tower will not be blown laterally when the fan (wind) blows.

C. Next, have the students add cross bracing to their tower while the tower is attached to the foundation. Have them turn on the fan again, and describe the effect of adding the cross bracing.

WHAT SHOULD OCCUR: The tower does not overturn. The cross bracing strengthens the tower so that it can withstand the wind load.

D. Finally, have the students place a load on top of the tower platform (use a book or a couple of books) and again turn on the fan.



ASK THE QUESTION: *Does the tower become more or less stable with a weight on the top?*

Students might think that the added weight makes the structure less stable, but the opposite is true. The weight acts in a downward direction and actually makes the structure more stable (assuming the structure is designed to support the dead load).

E. Discuss with students why water tanks on top of water towers are usually made from spherical or cylindrical shapes rather than from cubic shapes. The reason is that spherical and cylindrical shapes are more streamlined and therefore will be less subjected to wind loads.

THINK LIKE AN ENGINEER

From the student guide:
From what you learned in KSB 1 about surface area and volume of various geometric shapes, which of the above water tank shapes on page 15 of the KSB 4 student guide would create the least wind load assuming they all contained the same volume of water? (Answer is #1).

Why? Because the sphere is a more streamlined shape and is less subjected to wind load.

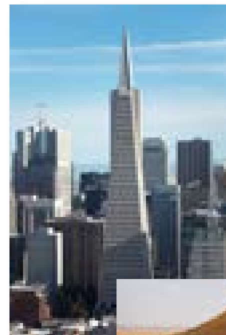
KSB 4E: Structural design is influenced by climate and location, function, appearance, and cost.

Ask the students to read the material in their student guide. Discuss why structures built in certain locations or climates take the shape that they do. Explain the notion of "form follows function."

Have students provide some examples of structures designed to be built in cities (where land costs are very high):
http://aibek.nomadlife.org/uploaded_images/tall_buildings-784313.jpg
http://inventorspot.com/articles/worlds_tallest_building_be_talle_6398

in earthquake susceptible areas; in deserts:
http://wps.com/BM/bluetarp_files/bluetarp.htm

and in permafrost:
http://images.google.com/images?q=houses+on+stilts&hl=en&rls=com.microsoft:en-US&um=1&ie=UTF-8&ei=LOeeS9yMIIG78gaNqcXtCw&sa=X&oi=image_result_group&ct=title&resnum=1&ved=0CBQQsAQwAA



Have the students explain how climate and location influence structural design.

Answers: Climate and location can both influence the form a structure takes. In cities, where land costs are high, buildings are built taller (skyscrapers); in areas where earthquakes are likely, buildings are strengthened using special construction techniques including cross bracing, and using rubber pads to cushion the structure when it shakes. On frozen soil, homes are built on stilts to prevent the heat from within the home melting the permafrost soil which would cause the homes to sink into the earth.

Ask the students to find examples on the Web (or from other sources) of structures of any type that were built for specific climates or locations. In the spaces provided in their student guides, ask students to copy and paste pictures of these structures and describe the environment for which they were built.

Discuss **COST** as an important consideration when designing and building structures.

Revisit the concept of *trade-offs* and introduce the concept of *optimization* as follows:

Sometimes, cost-benefit trade-offs are made. For example, changes are made in using less expensive materials. The architect may might decide to change the appearance and trade off appearance for cost. Or, an emergency shelter could be made so that it would withstand a heavy snow load but that might require more construction time. Designers and engineers have to consider these trade-offs constantly and make the best decision that strikes a balance between all the variables. Making decisions that balance all the variables is called *optimization.*

Discuss how appearance is another factor that drives design decisions. Some excellent examples are provided in the student guide:

This bamboo structure has an aesthetic appeal and blends into the natural environment.

http://www.bamboo-inspiration.com/bamboo-construction.html

Sir Ronald Storrs (the first British military governor of Jerusalem) enacted a bylaw in 1918 requiring that all new buildings use (or are faced with) Jerusalem Stone, to preserve the city's architectural style.

http://en.wikipedia.org/wiki/Jerusalem_stone

Summarize this KSB by having students work in groups to fill out the following table:

THINK LIKE AN ENGINEER

Since you are designing and building an emergency shelter, some design considerations are going to be much more important than others. **In the table below**, list the most important factors and also list those that are not important and might even be disregarded. In doing so, think about the main purpose of your shelter and the design specifications that you were given.

Critical Design Features for your Shelter	Explain Why this Feature is Critical

Shelter Design Features that are *not* Critical	Explain Why this Feature is not Critical

Here are some possible assessment questions that you may want to use with your students:

1. What types of loads have to be taken into consideration when designing a structure?

   Answer: dead loads, live loads, and wind loads. Also, in some climates, snow loads.

2. Why are water tanks made in a spherical or cylindrical shape rather than a different geometric shape such as a rectangular prism, a square-based pyramid?

   Answer: These shapes have lower surface area to volume ratios.

3. What function does a foundation serve?

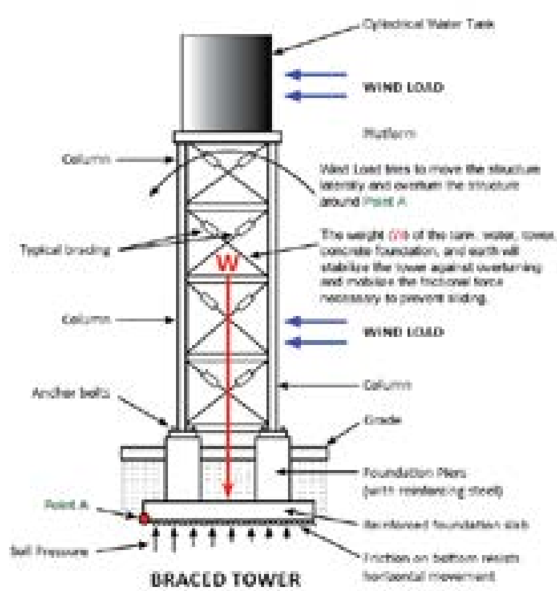
   Answer: It makes the structure more stable.

4. What design element principally provides a structure with the stability to resist overturning when it is subjected to wind load?

   Answer: A foundation.

5. In the diagram to the right, what loads did the engineer have to consider when designing the tower?

   Answer: Wind loads, dead loads (the weight of the tower and the water tank); and live loads (the water sloshing around in the tank).



6. Give an example of a trade-off that a structural engineer might have to make when selecting materials to be used in constructing a water tower.

   Answer: the shape of the water tank (chosen for wind load) vs. the ease of construction, the materials the tower is made from vs. the cost of the materials; the type of foundation vs. the cost and the time to construct.

7. Explain how structural design is influenced by cost and climate/location.

   Answer: Climate and location can both influence the form a structure takes. In cities, where land costs are high, buildings are built taller (skyscrapers); in areas where earthquakes are likely, buildings are strengthened using special construction techniques including cross bracing, and using rubber pads to cushion the structure when it shakes. On frozen soil, homes are built on stilts to prevent the heat from within the home melting the permafrost soil which would cause the homes to sink into the earth.

CHECK YOUR UNDERSTANDING - STUDENT GUIDE
KSB4 ANSWER KEY

Define dead load and give some examples. **Explain below** why dead load needs to be considered in structural design.

*Activity found in KSB4 Student Guide **page 5**.*

Define dead load and give some examples. **Explain below** why dead load needs to be considered in structural design.

*Activity found in KSB4 Student Guide **page 7.***

Specify whether each of the following is a dead load or a live load by **putting a check in the appropriate box**.

LOAD	DEAD LOAD	LIVE LOAD
Water tank itself	☐	
The tower itself	☐	
Wind	☐	
Water sloshing around in the tank	☐	

CHECK YOUR UNDERSTANDING - STUDENT GUIDE
KSB4 ANSWER KEY

Do you think a water tower is more or less stable when the water tank is filled or empty? **Explain your answer below.**

What do you think the **stability** of a structure refers to?
Select the correct answer below by placing a checkmark.

- ☐ **A.** Its ability to resist overturning and lateral (sideways) movement under load.
- ☐ **B.** Its ability to survive under any and all conditions
- ☐ **C.** Its ability to stand up under load, even without a foundation.
- ☐ **D.** Its ability to stand up even without any bracing.

Activity found in KSB4 Student Guide ***page 14***.

Activity found in KSB4 Student Guide ***page 17***.

1. In the space below, explain how climate and location influence structural design.

CHECK YOUR UNDERSTANDING - STUDENT GUIDE
KSB4 ANSWER KEY

Activity found in KSB4 Student Guide ***page 18****.*

2. Find two examples on the Web or other sources of structures of any type that were built for specific climates or locations. **Copy and paste pictures of these structures below in the spaces provided.** Then describe the environment **(in the spaces provided on the right)** for which they were built.

Structure 1	**Environment for which structure 1 was built**

Structure 2	**Environment for which structure 2 was built**

SHELTER DESIGN ACTIVITY

TO REITERATE: Once students complete the KSBs, they will form teams and will apply their knowledge and skill to the design of survival shelter.

When engaging in the design activity, students will work in teams to (1) apply the knowledge they have gained doing KSBs to the solution of the shelter design challenge; and (2) use an iterative informed design process. In doing so:

1. The teams will collaboratively apply their knowledge and skill to the solution of the given shelter design challenge by:
   a. Determining and defending their choice of shape of the shelter they propose to design;
   b. Demonstrating that the shelter dimensions meet design specifications;
   c. Calculating the surface area and volume of the shelter;
   d. Calculating the minimum R value of the shelter wall and determining the appropriate materials to use to provide the necessary insulation;
   e. Determining, through use of mathematical modeling, if their proposed shelter design will limit heat loss (in BTU/hour) to less than the heat generated by the body heat of the shelter inhabitants.

2. The teams will use an iterative *informed* design process to:
   a. research and investigate a design challenge;
   b. propose at least two alternative design solutions;
   c. choose and justify their optimal solution; Select the optimal shapes and make tradeoffs;
   d. develop a prototypical model;
   e. test and evaluate their prototype;
   f. redesign their solution; and
   g. communicate their achievements to an interested audience.

TEACHER SUPPORT

Present the shelter design problem to the students, making sure that the design specifications and constraints are clear (see Overview of This Design Activity, p. 1). Explain to the students that you will be forming four-person design teams and assign students to a team. In making your team assignments, try to form teams that include students with various levels of expertise.

GROUPING

If the class has students of both genders, be aware that research finds that:

> *in gender-balanced groups, males and females are equally interactive and showed similar levels of achievement; in majority-male groups, however, females tended to be ignored while males showed higher achievement than females. In majority-female groups, females directed most of their interaction to males to the detriment of their own interactions and showed lower achievement than males (Webb, 1984).*

The result of this study led Webb to suggest that children interacted better and learned more in gender-balanced groups or in all-female groups. However, Gillies and Ashman (1995) found that when students worked in **structured cooperative groups**, they became more responsive to each other's needs, irrespective of the ability and gender composition of the group.

Teachers should form groups, as opposed to letting middle school students select team mates. In this way, the teacher can ensure that the groups are gender-balanced (two girls, two boys, as opposed to three boys and one girl); that groups comprise students of various academic levels, and that expertise is distributed among groups.

BASIC ELEMENTS OF COOPERATIVE TEAMS
According to David and Roger Johnson (1994), there are five basic elements that distinguish effective cooperative learning, from simple group work. These are:

POSITIVE INTERDEPENDENCE
Team members perceive that they need each other in order to complete the group's task ("sink or swim together"). Instructors may structure positive interdependence by establishing **mutual goals** (maximize own and each other's productivity), **joint rewards** (if all group members achieve above the criteria, each will receive bonus points), **shared resources** (members have different expertise), and **assigned roles** (summarizer, encourager of participation, elaborator).

INDIVIDUAL ACCOUNTABILITY
Assessing the quality and quantity of each member's contributions and giving the results to the group and the individual.

(Continued on next page)

BASIC ELEMENTS OF COOPERATIVE TEAMS (cont'd.)

FACE-TO-FACE INTERACTION
Team members promote each other's productivity by helping, sharing, and encouraging efforts to produce. Members explain, discuss, and teach what they know to teammates. Instructors structure teams so that members sit knee-to-knee and talk through each aspect of the tasks they are working to complete.

INTERPERSONAL AND SMALL GROUP SKILLS
Groups cannot function effectively if members do not have and use the needed social skills. Instructors emphasize these skills as purposefully and precisely as job performance skills. Collaborative skills include instructorship, decision-making, trust building, communication, and conflict-management skills.

GROUP PROCESSING
Groups need specific time to discuss how well they are achieving their goals and maintaining effective working relationships among members. Instructors structure group processing by assigning such tasks as (a) list at least three member actions that helped the group be successful and (b) list one action that could be added to make the group even more successful tomorrow. Instructors also monitor the groups and give feedback on how well the groups are working together.

CLARIFY LEARNING OBJECTIVES

Remind the students that in order to construct their shelter, they must:

1. Consider more than one shelter design before making their final choice of shape and size.
2. Determine and defend the choice of shape of the shelter design.
3. Demonstrate that their shelter dimensions meet design specifications.
4. Calculate the surface area and volume of the shelter.
5. Calculate the minimum R value of the shelter exterior
6. From a variety available, select the most appropriate materials for the shelter exterior to that will provide the necessary insulation.
7. Determine and defend the choice of framing for their shelter design that will provide the necessary structural integrity.
8. From a variety available, select the most appropriate materials for the shelter framing that will provide the necessary structural strength.
9. Determine, through use of mathematical modeling, if their shelter design will limit heat loss (in BTU/hour) to less than the heat generated by the body heat of the shelter inhabitants.
10. Follow an "informed design" process to design a shelter as a contributing member of a design team.

DESIGN JOURNAL

Introduce the student design journal. Explain to students that this is a tool to help them develop an optimal design for their shelter. Lead students through the informed design process as scaffolded by the design journal. These steps include:

- Stating the design challenge
- Clarifying the specifications and constraints
- Considering at least two alternative designs
- Choosing and justifying the optimal solution
- Displaying the solution
- Explaining how the design was tested and evaluated
- Suggested modifications if the solution were to be redesigned
- Communicating achievements in a presentation to the class

BUILDING AND TESTING A SCALED SHELTER MODEL

It is likely that you will build a scale model of their shelter in lieu of a full-size shelter (which would be fine should you choose that option). For the scaled model, the objective is to observe the same difference in temperature as that of the full size model.

In order to achieve similarity between the scaled and full size model, we must make appropriate adjustments in the parameters that define the shape itself (i.e. length, height and width in the case of a rectangular prism), the material thickness, and the heat source.

We recommend building a ¼ scale model. All procedures below assume a ¼ scale model.

Scaled Shelter Design

1. Scale your shelter dimensions.

   Choose the instructions below based on your selected shape.

   - Rectangular Prism – make the length (L), height (H), and width (W) of the scaled shelter ¼ of the length, height, and width of the full size shelter respectively.
   - Square-Based Pyramid – make the base (B) and Height (H) of the scaled shelter ¼ of the base and height of the full size shelter respectively.
   - Cylinder – make the radius (R) and height (H) of the scaled shelter ¼ of the radius and height of the full size shelter respectively.
   - Hemisphere – make the radius (R) of the scaled shelter ¼ of the radius of the full size shelter.

2. Calculate an equivalent R Value.

The R value for your scaled model will be ¼ of the R Value of your full size design. You could achieve this by simply scaling the thickness of the materials you selected for your full size shelter. This will be a problem in many if not all cases, however, because these materials may not exist in the scaled thickness you need, or the material may not be allowed for the scaled model. For example, if the required R-value for your full size shelter is 2.0, then you must select materials (any available materials) to achieve an R-value of 0.5, or ¼ of the full size shelter R value.

If you cannot achieve an equivalent R value exactly, select materials and thickness to achieve an equivalent R value that is at least ¼ the full scale composite R value and as close as you can get. Note that the actual temperature difference that you will observe in the heat flow test will increase in proportion to this "error". For example, if your calculations show that your design will achieve an outside/inside temperature different of 30F and your actual equivalent R value is 30% higher than it is supposed to be, then you should see a temperature difference of 39F (30F * 1.3).

3. Scale the heat source.

The heat source for the full shelter is 1360 BTU/hr (4 human bodies). This heat source is simply scaled by ¼, which equates to 340 BTU/hr (1360/4). As a practical matter, we need to use a light bulb for our heat source so we need to convert BTU/hr to watts. We know that 1 Watt = 3.412 BTU/hour; so 340 BTU/hr = 99.65 Watts. Therefore, for a ¼ scale model, use a 100 watt light bulb for your heat source.

Example:

	Full Size Shelter	**Scaled Shelter**
Shape	Rectangular Prism	Rectangular Prism
Dimensions	L=8 ft W=8 fr H=4 ft	L=2 ft W=2 fr H=1 ft
Materials	1. 0.5 inch polyethylene (foam) roll 2. 0.5 inch cardboard • Composite R-value = 4.4	3. 0.25 inch polyethylene (foam) roll • Equivalent R-value = 1.1
Heat Source	1360 BTU/hr	340 BTU/hr ≈ 100 watt light bulb

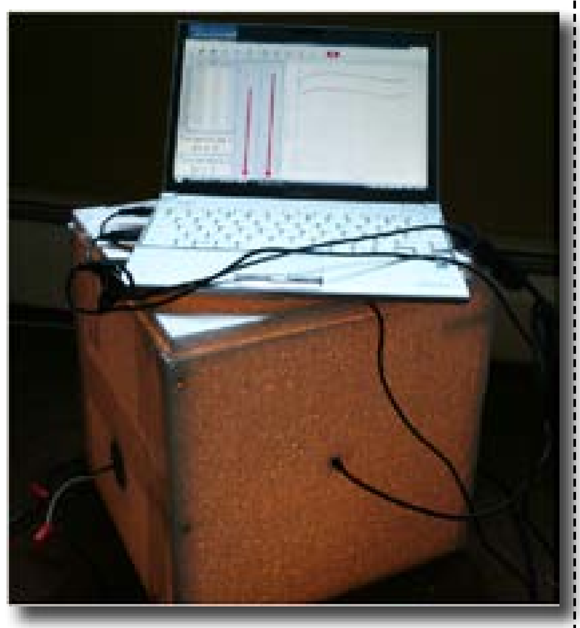
To observe the same difference in temperature between the scaled and full size model, we simply scale the dimensions, material thicknesses, and the heat source by ¼.

MATERIALS AND TOOLS

1) Structure (frame) materials:
   a) Birch Dowel Rods
   b) Balsa wood materials
   c) PVC Pipe
2) Insulation materials
   a) Plastic bags
   b) Foam Roll Cushioning
   c) Polyethylene sheeting
3) Tools and fasteners
   a) Twine
   b) Duct tape
   c) Hand shears (cutter)
   d) Utility knife
   e) Glue

HEAT FLOW TEST

To test the shelter model, you must measure the temperature inside and outside of your shelter to ensure that the inside temperature is at least 20F greater than the outside temperature. This is accomplished using temperature probes inside and outside of the shelter, as shown in the diagram below. The probes are connected to a USB port on a computer to display both inside and outside temperatures.



Probes that work well are Vernier surface temperature sensors (http://www.vernier.com/probes/sts-bta.html) and the Go-Link for each sensor (included).

These cost about $23 each. The sensor comes with a software program called Logger Lite (also included). http://www.vernier.com/go/loggerlite.html

1) Outside Temperature
   a) Your instructor will set up a probe to measure the outside temperature. Be sure to keep a record of this temperature as you take your own measurements as room temperature may increase with testing.
2) Inside temperature
   a) Place 2 inches of foam board insulation (R 3.3) on a table top. The dimensions of the foam board insulation should be cut such that the base of your scaled shelter will rest on top of the boards. The purpose of the foam board insulation is to minimize any heat loss through the "floor" of your shelter.
   b) Place the heat source (light bulb) inside your shelter and center it as well as you can.
   c) Tape the probe to a side wall of your shelter approximately 6 inches from the table top (or foam board). Do not cover the probe itself with tape.
   d) Observe the temperature on the computer screen until it reaches steady state (stops rising). This is likely to take at least 20 minutes.
   e) Record the maximum temperature inside the shelter.
   f) Record the room temperature (outside temperature).

WIND LOAD TEST

1) Remove the light bulb and probes from the heat flow test apparatus.
2) If you designed your shelter to include any staking, apply the staking.
3) Place a table top fan (which your instructor will provide) on the table approximately 3 feet from your shelter.
4) Turn the fan on its highest setting.
5) Rotate your shelter to test any movement as air hits your shelter from different angles.
6) Observe and record any movement in the shelter throughout the test.

Note: You cannot use a base for your shelter design as this would provide an unfair advantage in the wind load test. Your framing materials should rest directly on the foam board insulation.

SNOW LOAD TEST

1) Fill a number of 1 gallon freezer bags with sand. Place as much sand in the bag as it can hold while still being able to close the bag.
2) Flatten the sand out inside of the bag and place the bag on your shelter so that the sand is evenly distributed about the area covered.
3) Continue to place as many bags on your shelter as possible. Do not stack the bags, but be sure that the sides of the bags are touching.
4) Your test is complete when you can no longer add bags without them falling off, or when your shelter collapses.

Survival Master Presentation - Assessment Guidelines

After completing their design activity, student teams should make a presentation to the class that explains the process they undertook, the design decisions and tradeoffs they made, and the learning that occurred.

Students should clarify which decisions guided their choice of shelter design, why their group settled on a particular approach, and what tradeoffs they made in arriving at their optimal design.

Here is an assessment rubric *(on the following page)* for you, the teacher, to use in evaluating the student presentations. You may wish to share this instrument with students so that they understand how they will be assessed.

Note: This framework is adapted from materials provided by the Technology Student Association.

Survival Master Presentation Assessment	Participant Name or ID number				
EVALUATIVE CRITERIA					
Overall Presentation Quality (70pts)					
Introduction (interest and appeal) 10 pts.					
Clarity & sequence of presentation 10 pts.					
Students dressed well (business casual) 10 pts.					
Clarity of speech, pacing, pitch 5 pts.					
STEM Learning					
Did students explain what they learned? 10 pts.					
Did students explain the tradeoffs they made in arriving at their group design solution? 10 pts.					
DId students propose revisions based on what they learned? 10 pts.					
Did the students play an active role in developing and making the presentation? 10 pts.					
Use of Media					
Use of multiple types of media 10 pts.					
Quality of materials 10 pts.					
effective use (transitions, creativity) 5 pts.					
Total Points					
Comments:					

SURVIVAL MASTER PHYSICAL MODELING TIME LINE

A suggested time line follows.

Task	Planned Time in 40-minute Periods	Actual Time Taken
Introduction to Project Form teams Read over Student Activity Guide Introduction	2 periods	
Pretest, begin KSB 1	1 period	
Complete KSB 1	1 period	
KSB 2	3 periods	
KSB 3	2 periods	
KSB 4	5 periods	
Shelter Design Activity	5 periods	
Post Testing	1 period	
Debriefing	1 period	
Student Presentations	1 period	
Total Time	22 periods	

REFERENCES

Johnson, D., Johnson, R. (1994). Learning together and alone, cooperative, competitive, and individualistic learning. Needham Heights, MA: Prentice-Hall.

Webb, N.M. (1984). Sex differences in interaction and achievement in cooperative small groups. Journal of Educational Psychology, 76, 211-224

Gillies, R., and Ashman, A. (1995). The effects of gender and ability on students' behaviours and interactions in classroom-based work groups. British Journal of Educational Psychology, 65, 211-225.