DESIGN CHALLENGE

How to keep items cool in boiling water?

Lesson Overview

Grade Level
9 - 12

Duration
2 weeks - 2 months

Essential Question
How can the scientific method be used to come up with a solution to the problem of protecting an item exposed to a high temperature?

Design Challenge Summary

Students will design and construct a container that will keep items cool when placed in boiling water. A pat of butter will be placed in the container. The goal is to keep the temperature inside the container as cool as possible and prevent the butter from melting.

Objectives

Students will be able to:

- Design a solution to the challenge using the scientific method.

Concepts

- The scientific method can be used to find solutions to many problems.
- There can be more than one solution to a problem.
- Food, equipment and tools need to be kept at certain temperatures in order to maximize their effectiveness and maintain their structural integrity.

MESSENGER Mission Connection

The MESSENGER mission designers have come up with various ways to keep the temperatures on the spacecraft tolerable in the hot Mercurian environment.

This lesson was developed by the National Center for Earth and Space Science Education (http://ncesse.org).

Introduction to Design Challenges

Design Challenges are intended to focus on real-life situations that give students the chance to deal with many of the same issues with which scientists, engineers, and researchers are confronted in laboratories and offices.

Design Challenges provide motivating experiences for children by incorporating problem-solving, scientific approach, and cooperative teamwork into a standards-based activity. Students will discover their own and others' strengths as they take on different roles on a team, and they will witness firsthand the importance of both successes and failures, for they can learn from both.

Each member of the Design Challenge team is responsible for his or her part of the final project, whether it be research, drawing, building, analyzing, testing, or whatever may be required. There must be support and back-up from all team members to ensure the success of the whole team and of each individual member. The value in this type of a cooperative arrangement is its ability to allow for creativity and independence within a supportive environment, to teach responsibility, and to keep all students engaged in learning. Yet we do not lose sight of the value of healthy competition, and encourage teachers to use our criteria for judging each team's work, awarding the most successful in age- and grade-appropriate ways.

The Design Challenge may be used to prompt theoretical discussions in the classroom and further research only, or it may be used in its entirety, including the actual building of a working model. We recommend that at least one Design Challenge per year be assigned to the students, to give them the unparalleled experience of working together on applying the scientific process in their daily lives; it is sure to change their way of thinking in the years to come.

The Design Challenge is meant to encourage students to use a trustworthy scientific process for which they can provide a rationale, and which will yield verifiable results or answers to a question. While the scientific method has traditionally been taught in fairly rigid terms, we maintain that much creativity is, in fact, necessary within the basic methodology to best pursue any investigation thoroughly.

A scientist must be able to create research and design processes to fit an investigation, and keep well-documented records of each step so that the experiment and the results are verifiable by others. We include a guideline to help your students move through the scientific process, while providing for variations necessary to fit their individual designs and inventions.

Standards & Benchmarks

National Science Education Standards

Standard A2 Understandings about scientific inquiry

- Scientists usually inquire about how physical, living, or designed systems function. Conceptual principles and knowledge guide scientific inquiries. Historical and current scientific knowledge influence the design and interpretation of investigations and the evaluation of proposed explanations made by other scientists.

Standard E1 Abilities of technological design

- Identify a problem or design an opportunity: Students should be able to identify new problems or needs and to change and improve current technological designs.
- Propose designs and choose between alternative solutions: Students should demonstrate thoughtful planning for a piece of technology or technique. Students should be introduced to the roles of models and simulations in these processes.
- Implement a proposed solution: A variety of skills can be needed in proposing a solution depending on the type of technology that is involved. The construction of artifacts can require the skills of cutting, shaping, treating, and joining common materials—such as wood, metal, plastics, and textiles. Solutions can also be implemented using computer software.

American Association for the Advancement of Science, Project 2061

Benchmark 1B2 Hypotheses are widely used in science for choosing what data to pay attention to and what additional data to seek, and for guiding the interpretation of data (both new and previously available.)

Benchmark 1B4 There are different traditions in science about what is investigated and how, but they all have in common certain basic beliefs about the value of evidence, logic, and good arguments. And there is agreement that progress in all fields of science depends on intelligence, hard work, imagination, and even chance.

Benchmark 12A1 Know why curiosity, honesty, openness, and skepticism are so highly regarded in science and how they are incorporated into the way science is carried out; exhibit those traits in their own lives and value them in others.

Benchmark 12A2 View science and technology thoughtfully, being neither categorically antagonistic nor uncritically positive.

SCIENCE OVERVIEW

MESSENGER in Space

The concept of keeping comfortable in a hot environment is central to the success of the MESSENGER mission to Mercury. The MESSENGER spacecraft will venture into the inner parts of the Solar System, where radiation from the Sun will reach levels that are 5-11 times as high as they are near Earth, depending on where Mercury is on its orbit around the Sun. Since the Earth's atmosphere stops about half of all solar radiation from reaching the surface, the spacecraft will be exposed to more than 20 times the amount of solar radiation as it would on the surface of Earth. Infrared radiation emitted from the sunlit side of Mercury adds to the high-temperature environment. This has created a great engineering challenge for the mission design team: how can the spacecraft be protected from temperatures of over 400°C (750°F)?

The solution employed by the MESSENGER design team involves using heat-resistant materials, building a sunshade to protect the instruments from the Sun, and planning an orbit around Mercury that minimizes the amount of infrared radiation received from the planet's surface. As a result, MESSENGER instruments are in a thermal environment comparable to room temperature: during Mercury's orbit around the Sun, the temperature on the instrument deck of MESSENGER is expected to vary from a few degrees below 0°C (32°F) to 33°C (91°F).

High-Temperature Problems on Earth

Here on Earth, there are situations where we need to be able to withstand high heat. For example, firefighters have to stand and work right next to an intense fire. In today's world, there are many places where we need to have machinery and humans operate in high temperatures, from making steel to flying aircraft at high speeds.

The purpose of this discussion is to provide a glimpse of some of the science behind designing operations that take place in high temperatures. The question of how to keep things comfortable in a hot environment requires understanding such basic physical properties and processes as what temperature is, how heat moves from one place to another, and how this movement can be controlled.

Temperature and Heat

An object's temperature is a measurement that describes the level of motion and vibration in the atoms and molecules of which it is composed (that is, the internal energy of the atoms and molecules). The higher the temperature of an object, the more vigorously its atoms and molecules vibrate and bounce off each other, and the more disorderly is their motion. This means that heat flowing into an object increases the internal energy and disorder in that object, while heat flowing out of it decreases its internal energy and disorder. For example, the water molecules in a snowflake are arranged in an orderly pattern. If you hold a snowflake in your hand, it will melt and become a drop of water. While it melts, the orderly pattern of the snowflake changes into the more disorderly form of liquid water.

Thermodynamics

The science of thermodynamics studies the relationships between various forms of energy, such as heat and mechanical work. There are three basic laws of thermodynamics:

1) Energy may change form, but it is never created or destroyed ("conservation of energy"). For example, heat and chemical energy can be changed into mechanical energy by steam turbines and by automobile gasoline engines.

2) Heat energy flows from hotter to colder substances unless work is done.

3) There is a theoretical temperature at which matter would have the least possible internal energy and no disorder. However, it is impossible to reduce the temperature of any system to this absolute zero, 0 K (-273˚C; -459˚F).

Transmitting Heat

If you hold a snowflake in your hand, it will melt because the heat from your hand travels to the snowflake and causes its temperature to rise. In general, heat passes from one substance or an object to another by:

1) Conduction

- Heat moves through material without any of the material moving.
- E.g., the tip of a metal pitchfork placed in a fire: vibration of atoms is transmitted from the tip throughout the pitchfork, but none of the atoms move from the tip to other parts of the pitchfork.

2) Convection

- Heated material moves and carries heat with it.
- E.g., heating water in a pot on a stove: hot liquid from the bottom of the pot rises up, while cold water sinks down to be heated.

3) Radiation

- Heat is transmitted via electromagnetic radiation, either through a medium (such as air) or without need for material (e.g., through space).
- E.g., infrared rays, visible sunlight.

How Heat Changes a Substance

There are three basic ways in which heat can change materials:

1) Change in temperature

- The internal energy of the atoms and molecules of the material increases. This is the most common result of heat interacting with matter.

- The amount of heat needed to raise the temperature of one kilogram of a substance one degree Celsius is called the specific heat capacity (or just specific heat) of the substance.

- Two substances with the same mass but different specific heats require different amounts of heat to reach the same temperature.

- The specific heat of water is 4186 joules per kilogram per degree Celsius.

2) Change in size

- Since the motion of the atoms and molecules in a substance increases when heat flows into it, the atoms and molecules need more space and the substance expands in most cases.

- In contrast, when heat flows out of a substance, the atoms and molecules move more slowly and require less space; the substance contracts in most cases.

- All gases and most liquids and solids expand when heated. An important exception is water, which contracts when its temperature rises from 0˚C (32˚F) to 4˚C (39˚F), and only then starts expanding as it is heated. The same is also true when water changes phase from solid to liquid: water contracts when heated from ice to liquid. This property is caused by the way water molecules bond with each other in different phases; for example, in the solid state of water (ice), there is more empty space between molecules than in liquid water.

- The change in size is the basis for bulb-type thermometers, among other things.

- This effect must be taken into account when building bridges, buildings, and other structures, so that materials can expand and contract without causing severe problems.

3) Changes in the physical state (phase)

- Freezing: loss of heat causes a substance to change from liquid to solid.

- Melting: heat causes a substance to change from solid to liquid.

- Boiling: heat causes a substance to change from liquid to gas.

- Condensation: loss of heat causes a substance to change from gas to liquid.

- Sublimation: absorbing heat causes a solid to change directly into gas.

- Deposition: loss of heat causes gas to change directly into solid.

- Melting and freezing occur at the same temperature: melting and freezing point.

- Boiling and condensation occur at the same temperature: condensation and boiling point.

- The amount of energy that needs to be added or removed to change the state of a material is called latent heat.

Keeping Heat at Bay

In order to keep items cool, we need to keep heat from interacting with them. The movement of heat from one place to another can be restricted by insulation: by keeping heat from entering or flowing out of an object.

To combat the three ways in which heat can travel, there are three basic methods of insulation:

1) To fight conduction, some materials are used as insulators.

- E.g., many pots and pans have plastic or wood handles.

2) To fight convection, the space between hot and cold areas can be filled with "dead air."

- E.g., double-pane window: the layer of air between the outer and the inner windows stops the convection from transferring heat between them; narrow dead air space is better than wide since it makes the formation of convective air circulation currents more difficult.

3) To fight radiation, reflective or blocking materials can be used.

- E.g., reflective car sunshades placed against a windshield to prevent the inside of the car from heating up; sunscreen spread on skin to prevent sunburn.

Oftentimes, insulators are designed to combine different ways with which they can act to make them as efficient insulators as possible. For example, insulating material may be composed of poorly conducting material, have cell-like spaces to reduce the motion of cold or hot air, and be coated with reflective material.

Insulating material can be purchased in a variety of forms, such as blankets, paper, or in a loose, crumb-like form, and it may be composed of cellulose, fiberglass, gypsum, metal foil, perlite (glassy lava), rock wool (also called mineral wool), or plastics, for example. The type of insulation used depends on the specific needs of the application.

Insulation is used in houses to reduce the flow of heat outward during cold weather and inward during hot weather. Insulation is also used in many industrial applications to keep temperatures at a desired level in various processes. For example, industrial furnaces are sometimes lined with insulating blankets made of ceramic fibers so that high temperatures can be maintained inside it without damaging the surrounding equipment. Insulation is also used for fire-fighting suits and wherever high temperatures are encountered.

Insulation is also essential for spaceflight. For example, astronauts wear space suits composed of multiple layers of insulating material to shield them from the cold vacuum of space and the broiling heat of sunlight. Insulating materials can also be used to protect sensitive spacecraft systems and instruments, as necessary. For example, the MESSENGER mission to Mercury will have to operate in an environment where the temperature can reach over 400ºC (750ºF), and various methods are employed during the mission to keep the temperatures tolerable

Future

The use of insulation will allow us to employ ever more complicated tools and processes and allow us to venture ever more exotic environments. The development in this field is rapid, and new and better products are introduced constantly. This Design Challenge prepares students for these new developments, by having them explore the creative and scientific aspects of designing and making objects that can withstand high heat.

A Brief Guide on Using the Scientific Process in the Design Challenge

Professional scientists and researchers follow the scientific process when conducting scientific research and developing new concepts. The strength of the scientific method is that it takes away guesswork, beliefs and opinions. By following the process, a scientist or engineer can determine whether the proposed solution is robust enough to meet the standards set forth by hundreds of years of scientific progress. Although the steps are numbered for convenience, many scientists must return to previous work to reformulate a question, redesign a procedure, re-examine a plan, retest a hypothesis, etc. It would therefore not be unusual to have even more steps in an individual investigation. This overview has been designed to help students understand how the steps they take to come up with solution of the Design Challenge parallels the process a professional scientist, researcher, or engineer follows.

Using the scientific process, a scientist or an engineer:

1) States the problem or asks a question;
2) Conducts research to see what is already known, if an answer or solution already exists;
3) Proposes a possible solution;
4) Tests the proposed solution by building a prototype, conducting an experiment or making observations, and recording the results;
5) Analyzes results, then revises, rejects, or accepts the hypothesis, and reports conclusions.

The following steps describe what steps you would typically take to solve the Design Challenge by following the scientific method.

1) State the problem or ask a question

What Professional Scientists and Researchers Do:

Scientists and engineers spend a lot of time becoming familiar with a research area. They do this by studying specific areas in college, reading current research on the topic, and having discussions with other experts in the field. All of this happens before they embark on the process of developing informed questions about the topic. These questions then need to be answered through experimentation.

What You and Your Students Can Do:

The topic of the Design Challenge is to keep comfortable in a hot environment. You can have students research the ways with which scientists and engineers have grappled with the issue in various circumstances, from keeping food from spoiling in the kitchen to insulating industrial furnaces or keeping spacecraft comfortable when flying through Earth's atmosphere. After sharing information about their preliminary research, students should brainstorm. By doing this, students will formulate the critical questions which drive how they design and build their models later during the Design Challenge. Brainstorming gives students the opportunity to think of many ideas related to a particular topic. By brainstorming as a team, they can listen to each other's ideas and come up with even more ideas. Frequently, students will get more ideas when hearing and seeing the ideas of their teammates. Before beginning the brainstorming activity, make sure you lay out these basic rules to your students:

- Students must speak one at a time.
- Students must listen to each other.
- The ideas must relate to the question.
- There are no wrong ideas.
- The teams should come up with as many ideas as possible.

Students can keep track of their ideas by keeping a Brainstorming Journal. You can set the students in the spirit of brainstorming with the following question: How have previous generations grappled with the problem of keeping items (or people) comfortable in a hot environment?

After becoming familiar with the current state of research in their chosen topic, scientists and engineers typically develop an informed question that cannot be reasonably answered except through experimentation, research, or observation. To follow this procedure, the students could pick a specific topic proposed during the brainstorming session and refine it into a specific question to follow further. However, for this particular Design Challenge, the MESSENGER program provides the problem to be solved. The problem was chosen to be similar to what the MESSENGER engineering team had to grapple with: keeping comfortable in a hot environment. You can have the students come up with something similar to the following challenge by leading questions, such as "What kind of hot environments can we encounter during our daily lives—such as in a kitchen?" (if students suggest an oven, you may lead them to the idea of boiling water by suggesting that you might not have an oven available for testing—what would be another hot environment?) Or you can just pose to students the Design Challenge:

"How to keep items cool in boiling water?"

2) Conduct research to see what is already known and if an answer or solution already exists.

What Professional Scientists and Researchers Do:

Scientists and researchers conduct research not merely to determine if an acceptable solution has already been found to a problem, but to be inspired by the ideas of others who have attempted and failed. In this stage, they build upon their own experiences and those of persons before them to guide their investigation. By studying what did not work, you can learn without having to experience the failure yourself; this is one reason why it is so important to study history—so we don't make the same mistakes as our forefathers.

What You and Your Students Can Do:

Where to do research and gain insight into the attempted solutions by others depends on the nature of the original problem. For the proposed Design Challenge, we suggest that you start in the following places, but that you go beyond these few suggestions: Web sites, books, journals, magazines, and experts.

3) Propose a possible solution.

What Professional Scientists and Researchers Do:

With the necessary background information gathered, scientists and engineers can come up with a suggestion how to answer the question or solve a problem. Often, there are several external factors that play a part in their designs, such as a budget limitations, available technology, and sometimes even nature itself. This is when engineers and scientists use their ingenuity to find creative solutions. This is also the time when scientists and engineers come to a fundamental understanding of their solution. It is not enough to simply come up with a design—to be able to test and interpret the results correctly requires knowing exactly how it works.

What You and Your Students Can Do:

Have students brainstorm in their teams solutions to the Design Challenge based on the specific requirements and constraints set for the solution.

4) Test the proposed solution by constructing a prototype, conducting an experiment or observations and recording the results.

What Professional Scientists and Researchers Do:

Once a scientist or an engineer has come up with a proposed solution to the problem, the proposal can be tested. If the solution is a physical object, a prototype (the first of a kind of object) may be built based on the design, so that it is possible to quickly determine what works, and why in a real situation. Scientists and engineers must be able to deal with any unexpected challenges that may crop up during the testing of the solution. Not every test goes flawlessly, and often people rely on their creativity and ingenuity to help them overcome obstacles. At the same time, scientists and engineers are (ideally) rewarded with the first glimpses of their creation in action. This stage can be the most exhilarating part of the process, because it can be a chance to see the solution work—or, if it does not work, provide invaluable further insight into the problem.

What You and Your Students Can Do:

In order to see if your students' solution works, they must test it by building the model and following the testing procedures described in this Design Challenge. Make sure that the students write a plan that includes:

- Specific protocols and detailed procedures you intend to follow so you can answer the question (be prepared to explain why each step is necessary). You may have to make rough sketches of your invention.
- A list of the materials you will need, including tools for testing the success of your solution.

Charts and tables may be helpful in organizing your ideas.

- A calendar to schedule deadlines that you agree to meet, in order to efficiently complete your investigation.

Make sure that you check the students' proposed solution to ensure that they are following reliable, safe, rational, and reasonable procedures that account for or control unwanted intervening variables.

After the students have come up with a proposed solution, have them write a plan on how to test their solution, following the testing procedures described in the Student Worksheets. Have them include in their plan steps such as:

- The materials they will need.
- The steps of the experiment.
- A data table for collecting the measurements.
- Prediction of what will happen.

Whatever happens during this part of the process, be sure to record every step of the way, since it may be important in the final analysis of your results.

When possible, you may want to repeat this part of the process to verify your results.

5) Interpret and analyze results; revise, reject, or accept the proposed solution; and report conclusions.

What Professional Scientists and Researchers Do:

Once testing provides information, scientists and engineers can begin interpreting the results. Some interpretations of the results are immediately obvious, while others can take years of analysis to interpret. Sometimes, after the information has been looked at and shared with other scientists, ("peer review"), there is disagreement on what the information means. Who is right or wrong might not be determined until more tests are performed, but all points of view are important to consider. Regardless of the results or how they are interpreted, new questions invariably arise from such investigations, bringing us full circle in the scientific process.

An important aspect of the scientific process is sharing with other scientists your results and a description of the design and the testing your solution went through. Your solution can then be tested by others, if they so choose. This ability to replicate an experiment is at the heart of the scientific process—if an experiment or its results cannot be independently verified, the original results are deemed to have been wrong, because of over-interpreting the results, a glitch in the experiment or, in rare cases, due to forging of data or results. This is how real scientific results can be separated from forgeries and wishful thinking.

What You and Your Students Can Do:

Once your students have completed their tests, they need to look at the data they collected.

Make sure the students look objectively at their test results. Sometimes people want their solutions to work so much that they imagine more success than there really is. Be careful to base your conclusions only on what can be demonstrated from the actual object, testing, or calculations.

Have students hold a symposium to discuss their proposed solutions and results from testing. Have students contemplate improvements on their design after seeing their solution in action. If the design solution worked, are there ways to improve it? If the model did not work, what improvements could be made to make it work? Make sure other teams have a chance to contribute ideas to other teams' solutions. Teams can make improvements and then retest their designs. Or, you may choose to have the students work together, combine best elements from different teams' solutions and come up with the final class solution to the Design Challenge.

Lesson Plan

Preparation

- Divide the class into teams, or allow students to form their own. Ensure that each team has a variety of abilities represented evenly so that the team will be able to work well together.
- Decide how long you will give the students to design and build their projects, and if you want to use classroom time. This can be a project that takes a month or more, and for which you expect high-quality work, such as for a science fair. Alternatively, the project could proceed at a faster pace, perhaps in two weeks, and include time in class or during lunch to help certain groups.
- You may want to construct the testing apparatus in advance of the activity (see Student Worksheet for description of the testing procedures).

Materials

Per group:

- Materials for building the container—the solution to the Design Challenge: Chosen by the group within an assigned budget
- Thermometer
- Heat source
- Beaker capable of holding a 10 cm x 10 cm container
- Water: Enough to fill the beaker
- A skewer or a chopstick
- 1/8 c. of butter (2 tbsp.)
- Scissors or X-acto knives for making holes
- Scale or triple beam balance
- 2 ring stands
- 2 clamps

Warm-up & Pre-assessment

1. Pose one or two of the following problems to students: If you are hiking in the desert and want to stop and cool off a bottle of water you have been carrying, how can you do it? If you have dropped an object in a fireplace, how can you rescue it? How can you keep something hot once it is removed from a stove or oven? Help them come up with a clearly-worded, critical question about the object or circumstances under discussion.

Teaching Tip

Remind the students to remember some basic rules of brainstorming as described in "A Brief Guide on Using the Scientific Process in the Design Challenge."

2. Have the students brainstorm ideas related to the topic. Help them look for other categories or places in which the topic may have an effect. Based on their ideas, have students think up questions that they would really want to have answered but which are initially difficult to answer.

Procedures

1. Help the students understand the scientific process as described in "A Brief Guide on Using the Scientific Process in the Design Challenge." You may want to modify the depth of the tasks undertaken by the students in following the scientific process, depending on how much time you want to spend on the Design Challenge. The guidelines are intended to provide a comprehensive overview of the scientific process.
2. Go through the basic design requirements and the testing procedure with the students so that they understand what they need to design. These requirements and testing procedures are described in the Student Worksheet.
3. Remind students to keep clear journals of their design process. The documentation of the design needs to be comprehensible by anyone not associated with the project. In this manner, the design could be reproduced and re-tested by anyone interested. Adequate documentation is essential for maintaining the integrity of the scientific process in all endeavors.
4. Students will then test their platform design by following the directions on the Student Worksheet.
5. Make sure the water in the testing containers is boiling before the tests begin.

Note: You may want to have a fire extinguisher available during testing, in case there are any mishaps during testing.

Discussion & Reflection

Once a winner has been established, gather the students for an open discussion. Ask them to list ideas as to why the winning team was successful. Ask students to analyze methods or procedures that failed. Understanding why something did not work can provide as valuable insight into the problem as understanding why something else did work. Have the groups discuss how they could have improved their designs, and have a representative from each group explain their ideas to the class. Brainstorm ways in which the students could keep the container in the boiling water longer, if there were no budget constraints.

Curriculum Connections

- *Health:* Discuss the implications of getting burned, heat exhaustion, dehydration, other heat-related problems and their remedies.

Closing Discussion

Discuss with students the connection between what they have done and the MESSENGER mission to Mercury. Ask them how their challenge was similar to or different from the one that the mission engineers faced. Ask them how, even though their solutions were very different, were the processes similar?

Assessment

You can assign points in several different categories, to make sure the students understand the importance of the process as well as just the end result. The winner of the Design Challenge is the group whose butter melted the least. If there is a tie, they can be assessed on whether the temperature inside of their container increased.

Category A: How effectively the container insulated the pat of butter (important for meeting the challenge).

Points	**Percentage of Mass Lost**
10	Less than 10%
8	Less than 20%
6	Less than 30%
4	Less than 50%
0	Butter melted completely

Category B: How well the team documented the design process and the final design (important for the capability of repeating the experiment by others – essential for a proper scientific investigation)

Points	**Clarity of documentation**
10	Design could easily be repeated by others.
4	Document allows final result to be repeated but little documentation on process.
2	Documentation not clear on either final design or the process.
1	Documentation of the final design or the process missing.
0	No documentation.

Category C: How well the team documented the experiment (e.g., graphs; important for making sure the experiment results are verifiable by others and support the final results)

Points	**Clarity of documentation**
4	Clear documentation of the experiment.
2	Experiment documented but graph missing or unclear.
1	Experiment documentation not complete.
0	No documentation.

Final grade:

Grade	**Total points from Categories A-C:**
A	22-24
B	18-21
C	14-17
D	10-13
E	0-10

Design Challenge: How to Keep Butter from Melting?

Materials	Approved Materials for Constructing the Container
Per group: ▼ Thermometer ▼ Heat source ▼ Beaker capable of holding a 10 cm x 10 cm container ▼ Water: Enough to fill the beaker ▼ A skewer or a chop-stick ▼ 1/8 c. of butter (2 tbsp.) ▼ Scissors or X-acto knives for making holes ▼ Scale or triple beam balance ▼ 2 ring stands ▼ 2 clamps	▼ Metal ▼ Glass ▼ Cardboard ▼ Wood

Objective

Your goal is to design and build a container that can keep a pat of butter cool enough to survive in boiling water for ten minutes.

Specific Requirements of the Design Solution

▼ Your invention must consist of easily accessible materials, all of which need to be on the list of Approved Materials. The total cost of all materials must not exceed $10.

▼ The maximum volume of your invention is 1000 cm^3. The maximum dimension of one side or maximum diameter is 10 cm. For example, a cube with dimensions 10 cm x 10 cm x 10 cm will meet these requirements.

▼ Your invention must have a cover on top of it, and two holes must be made on the cover, each at least 1 cm in diameter. One hole will be used for inserting a thermometer (so the hole must be big enough to accept the thermometer used); the other hole will be used as a vent to let out steam.

▼ On the opposite sides of your invention, two 1 cm holes need to be placed 2 cm from the top of your invention. A skewer or a chopstick will be placed through these holes and attached to clamps on ring stands. This set-up will secure the container's position in the water, even if they would float otherwise. You must design the holes so that the container will not tip over during testing.

▼ Your invention must be submerged into the water a minimum of 5 cm, regardless of the density of the invention.

Teams

If you work in teams, we suggest you organize yourselves so that the members have the following roles:

Lead Scientist: Collects and maintains all team members' research information.

Design Engineer: Coordinates the designing of the solution.

Team Ambassador: Main liaison between teams. Keeps records of all collaboration.

Mission Specialist: Oversees team. Keeps team on task, using a schedule as a reference.

Writer: Incorporates team members' ideas into the project description.

Artist: Draws the illustrations to accompany the story, assists with technical drawings for the Design Solution. Creates Team Member Binders for the members.

You can have more than one person share tasks of a specific role. For example, you can have more than one Design Engineer in the team. Also, you may want to have backup persons for all responsibilities of the team in case a team member happens to be unavailable to fulfill their responsibility at a critical time, due to illness, for example.

ORGANIZE YOUR TEAM

Name	Roles	Primary Responsibilities	Back-up Responsibilities	Extra Work

In your team, remember to

▾ COLLABORATE

All team members can collaborate with other teams, asking questions as to how they might approach the problem, but the team ambassador should be informed when anyone does so. You may want to consider your invention as a "trade secret," until you put it into action, so be sure that your team is aware of how much you share with other teams.

▾ COOPERATE

Your team will come up with a better solution if you cooperate with each other. As a team member, make sure that you complete your tasks and then cooperate with the other members by sharing information, ideas, work, and compliments.

Guidelines

1. Your solution must be guided by the scientific process as well as by your own creativity.

2. If you work in teams, see Page 2 of the Worksheet for description of suggested tasks.

3. Research materials that are good insulators. Use a variety of sources (books, magazines, scientific and engineering journals, Web sites, CD-roms, DVDs) for research. Make notes of your research.

4. Based on your research and your ingenuity, choose a design solution.

5. You must write and illustrate a full description of your design solution. Keep in mind the following points:

- Include a section on how you made certain choices, decided to choose certain materials, if you conducted any preliminary testing, if you had to change plans, and at least two labeled diagrams or photographs of the solution.

- If you refer to information from a specific source which you encountered during your research and which influenced your design, make sure you cite it properly in your description.

- Comprehensive description of the invention and the design process is important so that others may evaluate your design at a later time.

6. Collect required materials.

7. Build your invention.

8. Test your device in class according to the testing procedures described on Page 5 of the Student Worksheet.

9. Write your final report. Write about your observations during the testing, what conclusions you made about the effectiveness of your solution, what you learned, and what your next investigation might be, based on your conclusions. Again, this is important so that others may evaluate your design at a later time or repeat your testing procedures and verify your results.

Testing Procedures

- Each group will receive one pat (1/8 c.) of butter. Determine its mass.
- Place the butter inside your container. Insert a thermometer in the hole on the top of the container and insert a chopstick or skewer through the two holes on the side.
- In a beaker, boil water over a heat source. Make sure there is enough water in the beaker so that the container can be submerged in the water by 5 cm (see next step), but not so much water that it will spill over when the container is added.
- Insert your container to a minimum depth of 5 cm into the boiling water (see Figure S1). Immediately take a temperature reading and record it in the Data Table on Page 6 for minute 0.
- If the temperature inside the container rises to within 5ºC of the maximum temperature on the thermometer, stop the experiment immediately, and record the time and the final temperature on the Data Table.
- Record the temperature every minute for the next ten minutes in the Data Table on Page 6.
- Remove the container from water.
- After allowing the container to cool for 5 minutes, determine the mass of the remaining unmelted butter. Observe the shape of the butter.

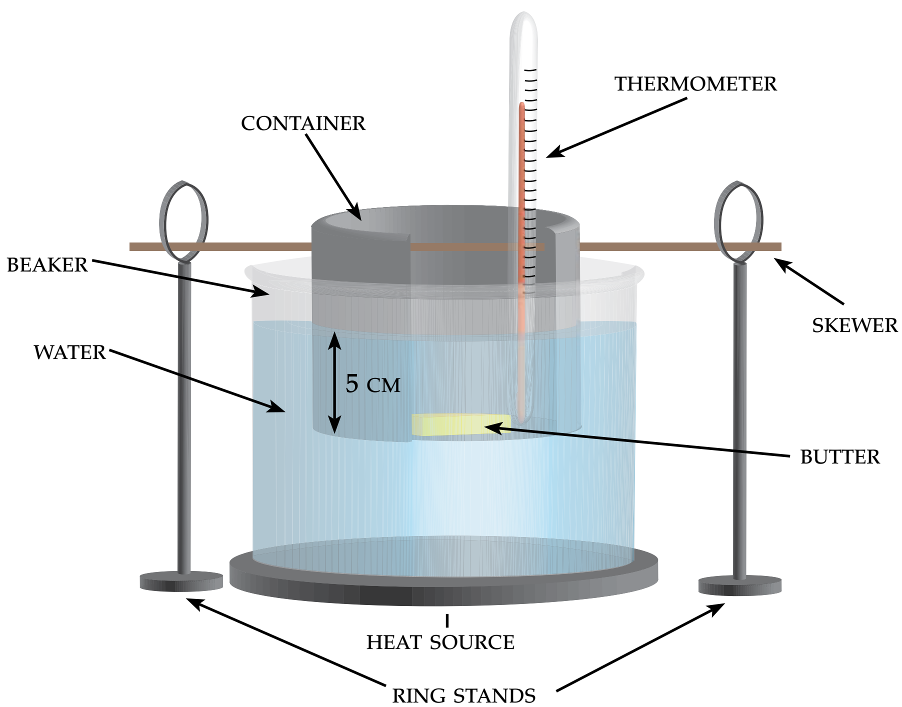

Figure S1. The setup for testing the effectiveness of your container. Place the butter inside the container. Insert a thermometer through a hole in the cover. Place the container in boiling water to a minimum depth of 5 cm. Be careful not to spill water out of the beaker when inserting the container in it.

	Mass of Butter (g)
Before Entering the Boiling Water	
After 10 minutes in Boiling Water	
Difference in Mass	

Observations: The shape of the butter

Data Table

Minute	Temperature
0	
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	

Make a graph of the temperature of the container versus time.