In terms of the magnitude of effect on human history, few discoveries have been as powerful as the discovery that heat could be used to do work, a discovery made by scientists in the mid-1800's.

The technical name for this discovery is "Conservation of Energy" since one of the implications was that energy cannot be created or destroyed. Before about 1840, it was known that sometimes mechanical work made things hot but the heat often seemed to disappear. Conservation of energy showed people that the "disappearing" heat was actually changing into energy of another form and these other forms could be used to power machines. Thus began the industrial revolution, the rise of the working class, the building of cities, and the explosion of modern technology. Thus also began smog, toxic landfills, and global warming, but those are subjects for another day.

This module focuses on a special kind of work: the work that can turn a solid into a liquid or a liquid into a gas. These processes are called "changes of phase" and they are very important to understanding how the world works and what makes it habitable for life.

Begin by asking yourself some questions about changes of phase that we see around us. The next few questions are designed to get you to think about your ideas so it is okay to be wrong. You will come back to these questions later.

- After a heavy snowfall, the weather can warm up enough that temperatures remain above freezing for several days, and yet one can often see piles of snow lying around here and there. Why do you think this is so? Why doesn't the snow melt as soon as temperatures rise above freezing?

- Here is a hint aimed at getting you to think about what is necessary to melt the snow. When the temperatures are above freezing, leftover snow usually melts much faster if it rains. Why is that? What do you suppose it is that the rain carries in greater quantities than the surrounding air?
• "Steam burns" are notoriously more painful than other kinds of burns. This is confirmed by solid scientific tests. A gram of water vapor at 100 °C would indeed burn your skin much worse than a gram of liquid water at 100 °C would do. Why do you suppose this is so?

• Our skin produces sweat to cool us down. The sweat is the same temperature as our bodies (maybe a little warmer) when it reaches the skin, but soon it cools us down. Why do you suppose this is so?

• Paramedics away from sources of cold water often will treat patients for hyperthermia (overheating) by wiping their skin with room temperature alcohol instead of room temperature water. This might seem strange based on what you have learned about water. What advantage do you think the alcohol might have? (It usually has nothing to do with killing germs.)

• "Thunderheads" are the tallest clouds. They typically form low in the sky as huge amounts of water vapor condenses into liquid droplets (and solid crystals). As this happens the surrounding air moves upward fairly quickly, carrying more vapor with it. As this new water vapor condenses, it causes more air to move upward, carrying new vapor and repeating the process until a very tall cloud is formed. Why does this happen? What is causing all of this air to move up?

We will come back to those six questions and a few more at the end of this module. For now it is time to do some "research." This is the point where you would normally grab equipment and start doing experiments. The problem is that experiments on changes of phase take a very long time and students don't learn much from watching water boil.
So for this module we return to the time-honored technique of the gedanken-experiment. We will think about research while looking at data from imaginary experiments that are actually far too clean and perfect to have come from an ordinary lab.

**Experiment #1: Melting ice.**

We imagine a perfectly insulated system where we can add any amount of heat to the object we want (and only to the object we want) and look at the results. Below is a graph of what happened when 4500 calories was added to a 100 g block of ice, originally at a temperature of -50°C.

- The temperature of the block of ice continuously changed as the first 2500 calories of heat were added. How much did the temperature change? For how much ice? For how much heat? Based on the data in this graph, what is the specific heat of ice?

- After the temperature of the ice rose to 0°C, the temperature quit changing. What do you suppose was happening here?

- Upon looking in the container, it was discovered that although the container was perfectly insulated, there was a small amount of liquid water in with the ice. The block of ice now has a mass of only 75 grams while there were 25 grams of liquid water. What created the 25 grams of liquid water?
The temperature of the 100 g of “H2O” did not change as the last 2000 calories were added. The H2O just changed form, or “changed phase.” If 2000 calories melt 25 grams of ice, how much heat is required to melt one gram of ice?

The quantity you calculated above is called the "Heat of Fusion" of ice. You might think that "Heat of Melting" makes more sense, but the term "heat of fusion" has been around for a long time. It has units of calories per gram. Here are the heats of fusion of some other substances:

- Nitrogen: 6 cal/g (yep, somebody had to make solid nitrogen)
- Sulfur: 9 cal/g
- Silver: 21 cal/g
- Copper: 32 cal/g
- Ethyl Alc.: 24 cal/g
- Water: 80 cal/g

What do these numbers tell us about our old friend water?

The graph above shows a continuation of our previous experiment when 13,000 calories of heat are added to our 100 g of ice (the numbers above the dots show calories at those points). Explain in words what is happening in this graph.

Explain in your own words what the heat of fusion tells us about a substance.
Experiment #2: Boiling water

We now take our perfectly insulated system, pour in 100 g of water at a temperature of 87° C, and add 4000 calories of heat.

- Based on what you know about water, how much heat should it take to raise the temperature of 100 g of water from 87° C to 100° C? Does that agree with what you see in the graph?

- The last 2700 calories added to this system don't seem to have changed the temperature at all. What do you suppose is going on here?

- Opening the container reveals that there are only 95 grams of water in the container. The rest of the water appears to be just plain gone! Where do you suppose this water went?

*Technical note:* If you said that 5 grams of water turned into steam, that’s not exactly right. Steam is a bunch of LIQUID water droplets suspended in air. A droplet is large enough to see with a magnifying glass. It contains billions of water molecules. In order for water to disappear it has to turn into water vapor which is invisible. In water vapor the individual molecules are separated so you can’t see any droplets.
- If it takes 2700 calories to vaporize 5 grams of water, how much heat does it take to vaporize one gram of water?

The quantity you calculated above is called the "Heat of Vaporization" of water. Just like heat of fusion, it has units of calories per gram. Here are the heats of fusion of some other substances:

- Nitrogen: 48 cal/g
- Sulfur: 78 cal/g
- Mercury: 65 cal/g
- Ethyl Alc.: 205 cal/g
- Water: 540 cal/g

- What do these numbers tell us about our old friend water?

- Which takes more heat: vaporizing a gram of water or melting a gram of ice? A little more or a lot more?

The graph above shows a continuation of our previous experiment when 77,000 calories of heat are added to our 100 g of ice, originally at a temperature of -50°C. Explain in your own words what is happening in this graph.

- Explain in your own words what the heat of vaporization tells us about a substance.
Now try these questions again:

- **After a heavy snowfall, why doesn't the snow melt as soon as temperatures rise above freezing?** What does the snow have to "absorb" as it melts?

- If the snow absorbs what you said it absorbs from the surrounding area as it melts, what will that do to the area around the snow?

- Leftover snow usually melts much faster if it rains. Why is that? What do you suppose it is that the rain carries in greater quantities than the surrounding air?

- "Steam burns" should be called "water vapor burns." A gram of water vapor at 100 °C burns worse than a gram of liquid water at 100 °C. Why is this so?

- Sweat is the same temperature as our bodies (maybe a little warmer) when it reaches the skin, but soon it cools us down. Why is this so?

- Paramedics cool patients by wiping their skin with room temperature alcohol instead of room temperature water. The data in this module shows a disadvantage that alcohol has compared to water. What advantage might alcohol have?

- "Thunderheads" become tall as invisible water vapor condenses into liquid droplets and then into ice crystals. Why? What happens to the surrounding air as the water changes phase? What causes this air to move up?

Check your answers with an instructor.