HEAT AND CONSERVATION OF ENERGY

I. INTRODUCTION

A. Overview of the Unit

In this unit students develop a model for the conservation of energy that is built from a variety of investigations utilizing fairly simple materials such as mixing varying amounts of water at varying temperatures. Students then use this model to predict other events, such as the resulting temperature that occurs when there is an exchange of heat energy between water and metals, which leads them to the need for specific heat and the need to revise their initial water-derived conservation of energy model. Students also observe melting ice cubes and other phase changes to further strengthen their ability to distinguish between heat energy and temperature. The concept of temperature of course plays a central role in the measurement of the systems they are dealing with.

B. Acknowledgments and Origins of Ideas

Ideas, concepts, activities, and direction for this module have come from a variety of sources. They include:

- Conceptually Oriented Program in Elementary Science (COPES) (Morris Shamos, 1965),
- J. Wessner and L. Ukens, *Activities in Physical Science - A Nontext*, used in physical science course at Towson State University, Towson, MD. (Wessner and Ukens, 1993),
- Heat Module, *Operation Physics* (AIP, 1990).

C. General Safety Considerations

The materials used in the Heat and Temperature unit are common materials and require minimal safety concerns. The primary safety measures will be the use of eye protection whenever students are lighting alcohol burners, handling hot water, and mixing various substances, some of which will reach high temperatures. Students should be warned not to touch any object of unknown temperature. Normal precautions should be given for the handling of glass beakers, test tubes, and thermometers. Safety rules for physics can be found in the American Association of Physics Teachers publication *Teaching Physics Safely* (Peterson, 1985).

II. STUDENTS' NOTIONS ABOUT HEAT AND CONSERVATION OF ENERGY

A. Students' Prior Beliefs as Described in the Research on Student Conceptions

An excellent source of information on student notions about heat and temperature is *Aspects of Secondary Students' Understanding of Heat: Full Report* (Brook and others, 1984) . Within this report are additional articles that address specific elements within heat and temperature. Articles by Driver (Driver and Russell, 1982) , Tiberghien (Tiberghien, 1980) and others are also helpful.

Teachers' Conceptual Understanding

Students are not the only persons who harbor alternate beliefs about heat energy and temperature. Krajicik and Layman (Krajicik and Layman, 1989) carried out a project that gave them the opportunity to monitor the conceptual understanding of a group of middle school teachers. Interviews with 11 experienced teachers indicated that they harbored alternate conceptions of both temperature and heat energy. For example, 7 of the 11 teachers participating in the pre-introductory workshop interviews believed that temperature was a measure of heat energy. The teachers then participated in a three-week workshop that involved many experiments on heating and cooling. After the introductory workshop, 8 of the 11 teachers held satisfactory scientific views of temperature. However, in spite of this improvement in the concepts of temperature, many teachers still held alternative concepts or had incomplete ideas regarding heat energy, and most teachers exhibited weak understandings of how to teach heat energy and temperature concepts both before and after the introductory workshop.

Students' Naive Ideas as Outlined in *Operation Physics* (AIP, 1990) Heat Unit

1. Heat is a substance.
2. Temperature is a property of a particular material or object.
3. The temperature of an object depends on its size.
4. Heat and cold are different, rather than being opposite ends of a continuum.
5. When temperature during boiling remains constant, something is wrong.
6. Boiling is the maximum temperature something can reach.
7. Ice cannot change temperature.

8. Objects of different temperatures that are in contact with each other, or in contact with air at a different temperature, do not necessarily move toward the same temperature.
9. Heat energy only travels upward.
10. Heat rises.
11. The kinetic theory does not really explain heat transfer.
12. Objects that readily become warm (conductors of heat) do not readily become cold.
13. The bubbles in boiling water contain "air," "oxygen," or "nothing," rather than water vapor.

Other Naive Student Ideas at the Fourth-Grade Level as Detected by Gale and Layman (Gale and Layman, 1992)

14. Some things do not have temperature.
15. Air plays a major role in something experiencing a temperature change.
16. As two substances come to an equilibrium temperature, there remains a small difference in temperature.

Monitoring Student Conceptual Change

An article on thermodynamics by Kesidou and Duit (Kesidou and Duit, 1993) points out the importance of rendering visible the explanations, stories, models, etc., of the students after they have provided seemingly correct answers about their conceptions of heat, the conservation of energy, and temperature. Student explanations can be naive but still yield correct answers under multiple choice conditions. Many do not have the scientists' preferred conceptions even though they have supplied seemingly correct answers. Their alternate conceptions must be rendered visible in a truly metacognitive fashion to both the students as well as the teachers. With very skilled teachers and learners whose learning abilities are enhanced by a consistently applied constructivist approach, students could experience a broad recognition of the improvement of their personal models of heating, cooling, change of state, temperature, temperature equilibrium, and the evolution of their appropriate explanations for these conceptions.

One outgrowth of the monitoring of the students' conceptual state as they carry out the activities designed to modify their conceptions should be to ask students after each of our separate sections or after a finite number of exercises, to look for personal evidence that they have experienced cognitive or conceptual change. The notes that they make in the margins of their Student Activity Sheets, after the class discussion and following the activities, may provide strong evidence of this conceptual change.

B. Conceptions that Students Should Develop

Not all of the previously listed naive conceptions will be dealt with in these activities. The concepts to be addressed are:

1. The Difference between Temperature and Heat

The scientific concepts of heat and temperature will not develop until the students have carried out their series of observations and developed their model for predicting the final temperature of a mixture of things having different temperatures, different masses, and being made of different materials.

The intensive property of temperature (not dependent on the amount of material) vs the extensive property of heat (proportional to the amount of material) energy must finally be recognized by the students.

2. Temperature Equalization

This is a good example as described in Kesidou and Duit (Kesidou and Duit, 1993) of students providing correct responses to questions relating to temperature equilibrium but justifying these ideas with explanations that differ from the physicist's. Students must succeed in refining their explanations even when they would seem to provide correct answers.

3. Development of a Model

The primary model to be developed by the students will be a predictor of final temperature when things are mixed together. The series covers water vs water with various mass and temperature combinations. This will later be modified to include different materials. This modeling approach is used effectively by David Hestenes in an effort to improve the conceptual understanding of introductory physics students (Hestenes, 1993).

4. The Characteristics of a Model

As students apply their personally developed model for water and other substance mixing, they must learn to recognize the character and value of a model. They will have an opportunity to modify a model when their original mixing of water model no longer properly predicts the case where different substances are involved.

5. Specific Heat

The need for the concept of specific heat will arise when students attempt to predict the final temperature of a mixture of a metal mass within a water mass. For instance, when the prediction of the final water temperature is much too high, it brings into play the difference between water and metal.

6. Latent Heat of Fusion

A critical experiment for students is one in which energy may be going into and out of a system that is not experiencing a temperature change. This also allows students to observe temperature plateaus that occur at different levels for different substances. An ice plateau should also be a part of this system, with perhaps temperature sensors placed in the center of an ice cube to contrast its constant temperature with the surrounding water that continues to cool as the ice continues to change state.

7. Latent Heat of Vaporization

The existence of a temperature plateau at a change of phase provides a second opportunity for students to study a substance that is receiving energy but not experiencing a change in temperature. This provides a second example to support the distinction between heat and temperature.

8. Increasing Disorder

Increasing disorder is a natural process associated with heat energy.

Student's conceptions of irreversibility (Kesidou and Duit, 1993) are nicely discussed and should be stressed in these experiments as well.

9. Heat Conductors and Insulators

Modern understanding of energy resources and conservation requires an understanding of the role of conductors and insulators in thermodynamics. This will come up in the discussions even though there is not a separately designed experiment to deal with these concepts.

10. Other Forms of Energy

Conservation of energy emerges as a theme for the Heat and Conservation of Energy unit. It is important to have students recognize through suggestion and discussion various forms of energy beyond the experiments carried out in this section and to realize that energy is conserved in all cases.

III. COGNITIVE RATIONALE

The theoretical base chosen for the project, which includes Guiding Principles for the Design of Modules, the *Powerful Ideas in Physical Science* Filter Questions, and the Phases and Methods of Approach, serves as an excellent base for the heat and temperature work.

This base honors the constructivist view of learning and provides procedures to be built into the student activities associated with each concept.

Identification of Alternative Approaches

General Comments

While this module is specifically designed for small group activity, the development of concepts and general flow of activities will work well for larger groups. In large-class settings with separate laboratory sections many of the present activities can easily be done as demonstrations instead of hands-on activities. When doing them in this fashion, make sure you involve the students in such tasks as temperature reading, data collection, etc. You may also need to use larger displays for the temperature readings. Even in large-class settings students can collaborate with other nearby students to preserve small group advantages. The last two investigations are particularly designed to work well with large or small groups.

Specific Comments

Instructors should carefully schedule and sequence activities so that those performed in the smaller laboratory sections inform and correlate with the lecture and demonstration activities. In general, students should experience the ideas presented in the laboratory or lecture demonstration prior to the lecture discussion of those ideas. Allowing limited time for small groups of students in the lecture to discuss and share their ideas about demonstration phenomena or prior laboratory experiences can be rewarding for students and provide the instructor with meaningful insights into student thinking about how they are processing this information. Any excuse for group work, small or large discussions, or individual writing activities that allow students the opportunity to negotiate the meaning of their experiences and to make sense for themselves of these powerful conceptual ideas is time well spent.

IV. INSTRUCTOR NOTES

A. Equipment List

Equipment	Per lab group of 4	Per class for demonstration	For unit
Styrofoam™ cups	3		
Thermometer or microcomputer based lab (MBL) probe	1		
Plastic medicine cup	1		
Containers for water	3		
Glass beads	20 cm^3		
Plastic beads	20 cm^3		
Copper beads	20 cm^3		
Flat paper towels	1		
Flat wooden plates	1		
Flat aluminum plates	1		
Flat copper plates	1		
Set of masses	1		
Brass object	1		
Aluminum object	1		
Copper object	1		
Tongs	1		
Steel washers	1		
Alcohol lamp	1		
Test tubes	4		
Beakers as test tube holders	4		
Steam boiler		1	
Burner stand		1	
Bunsen burner or hot plate		1	
Pairs of wooden spheres connected by rubber bands	4		
Magnets	8		
Simple pendulums (mass on string)	4		
Mechanical toy	1		
Flashlight	1		
Balloons	4		
Can (e.g., brake fluid can)		1	
Cork to fit in can		1	
Butane lighter		1	
Small electric motor (e.g., as in electric car)		1	
Matched tuning forks		1 pair	
Baby food bottle with lid			8
Transparent walled container with partitions			1

Consumables	Per lab group of 4	Per class for demonstration	For unit
Ice cubes	4		
Graph paper	4 pages		
Hot water	500 cm^3		
Cool water	500 cm^3		
Sand	500 g		
Salt	500 g		
Isopropl alcohol	500 cm^3		
Boiling water	1000 cm^3		
Paradichlorobenzene	10 mL		
Napthalene	10 mL		
Paraffin	10 mL		
Ice	100 g		
Food coloring		1 bottle	
Cheap cologne or perfume		1 drop	
Rice	500 g		
Beans	50 g		

B. List of Student Investigations/Activities

Focus on Science

Investigation H1: **Melting Ice**

Focus on Science H1.1: Melting and Energy Exchange

Investigation H2: **Telling Hot from Cold**

Focus on Science H2.1: Sensing Temperature

Investigation H3: **Conservation of Energy Model Development**

Focus on Science H3.1: Temperature and Heat
Focus on Science H3.2: Equilibration Temperatures

Investigation H4: **Change of State**

Focus on Science H4.1: Winter Roads and Ice Cream Making
Focus on Science H4.2: Temperature Plateau and Nighttime Temperatures
Focus on Science H4.3: Latent Heat of Vaporization and Fusion

Investigation H5: **Other Forms of Energy**

Focus on Science H5.1: Energy Storage and Transformation

Investigation H6: **Disorder**

Focus on Science H6.1: Disorder and the Transfer of Heat Energy

Homework

Investigation H1: **Melting Ice**

Homework H1.1: An Olympic Event

Investigation H2: **Telling Hot from Cold**

Homework H2.1: Hot and Cold

Investigation H3: **Conservation of Energy Model Development**

Homework H3.1: Mixtures and Specific Heat

Investigation H4: **Change of State**

Homework H4.1: Change of State

Investigation H5: **Other Forms of Energy**

Homework H5.1: Changes in Energy

Investigation H6: **Disorder**

Homework H6.1: Disoryder