A COMPARISON OF THE TREATMENT OF HEAT AND TEMPERATURE AT THE MIDDLE SCHOOL LEVEL IN GERMANY/BAVARIA AND CANADA/MANITOBA

by

Victor Frank Sawatzky

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Abstract

This thesis compares curricular and textual documents from Germany/Bavaria and Canada/Manitoba with regard to the central topic of heat and temperature. Such a comparison reveals the importance of recognizing the differences in age and societal background when selecting the concepts that are to be studied. The local environment of the children must be considered when chosing the exemplars to illustrate the scientific concepts.

Children learn about the world through their sensory perceptions and form conceptions that are satisfactory to them even though they are often contradictory. These conceptions are often called "preconceptions" when the child enters the classroom and encounters the concepts of science. The role of the teacher is to lead the child from the preconceptions to an understanding and acceptance of the "scientific" concepts. Education research clearly shows the "robustness" of these preconceptions. In response to this problem, some researchers argue that the preconceptions and the language used need not be discarded if emphasis is placed on teaching the student the importance of a particular context of usage. Indeed, some preconceptions may actually be useful in the development of scientific concepts.

The historical development of concepts regarding heat and temperature involved a concept that seems to be such a natural preconception in children, namely the idea of caloric. This thesis argues that the notion of caloric can become a useful pedagogical device until the student is intellectually capable of understanding the more complex, scientifically accepted explanation.

The concepts of heat and temperature were considered to be equivalent until the mid 18th century when the development of accurate thermometers made it possible for scientists to differentiate between these two concepts. It is with these two concepts that the discarded "caloric" theory of heat can be used effectively in teaching students the difference between heat and temperature. By using the caloric theory, teachers can, in a sense, replicate the historical development as they teach these concepts. The kinetic molecular theory can then be introduced as a natural progression to present-day scientific understanding.

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Chapter 1. Introduction and Rationale

Introduction:

I spent the school year of 1982-83 as an exchange teacher in West Germany. When the principal discovered that I was a science teacher who spoke German he immediately suggested that I teach science at the grade 5, grade 6 and grade 8 levels. Since there was a shortage of science teachers in Germany at that time, the principal urged me to teach science exclusively. This was clearly an unusual situation since North American teachers are most often assigned and expected to teach English language courses only. I was given four grade 5 classes, four grade 6 classes and five grade 8 classes. Each class consisted of 25 - 30 students. One consequence of this assignment was that each class was allotted only one 45 minute period of science instruction per week in grades 5 and 6 and one and one half 45 minute periods in grade 8. Another, more fortunate consequence was that I was able to teach only science and was thus in the position to learn about science teaching in Germany and to enjoy a reduced work load.

When I approached Dr. Stinner to discuss a thesis topic, he suggested that I define a problem based on my teaching experience in a German school. Being fluent in German and acquainted with German science education, Dr. Stinner seemed to be the ideal person to advise me on such an undertaking.

After some reflection I decided to investigate what the literature has to say regarding the teaching of the central concepts of heat and temperature. In order to connect the literature information to my experience in Germany, I also wanted to compare the treatment of the important topic of heat energy at the middle school level in Canada/Manitoba and Germany/Bavaria as presented in the respective curriculum guides and current texts. Surprisingly, there are few comparisons of this kind in the science education literature. While there are reports of international test results, comparisons of specific content and the corresponding teaching approaches have not been made. In fact, I could not even find comparisons of specific subject matter as presented in textbooks. Moreover, there seems to be no literature that compares the teaching styles in the two countries. What I did find was a description of physics instruction in various European countries, Dreyer (1992), Grim et al. (1992), Henderson, (1992), Holec et al. (1992), but I could find no detailed comparisons. Therefore, the comparison I am undertaking may be the first of its kind and I will therefore not be able to answer more than a few of the questions that might be asked nor will I be able to address many issues concerning the topic.

In view of the findings of developmental psychologists (Piaget and others) that students' conceptual development in science follows much the same sequence as the historical development of these concepts, the following questions suggest themselves:

1. What does history tell us about how the concepts of heat and temperature were developed?

2. What are the recent findings about students' common-sense pre-science conceptions relative to the topic of heat and temperature? Further to this, to what extent are any of these pre-science conceptions useful in the teaching of the scientific concepts of heat and temperature?

3. How do the curricula and related texts of Germany/Bavaria and Canada/Manitoba compare as to concept presentation?

4. What implications for the science classroom teacher does the literature and the comparison of the curricular materials and textbooks suggest?

These are the questions that will guide my reading and study of recent literature, the curriculum guides and the textbooks.

Chapter 2 Framework and Methodology

Educational Jurisdictions

The comparison of curricula and texts that I am undertaking involves two widely separated educational jurisdictions. Bavaria, is a "Land" (state) situated in the southern-most part of Germany and has been in existence for many centuries. Its culture and educational practices have developed throughout many centuries. According to a recent curriculum publication produced by the Education Ministry in Munich, its education policies are held in great esteem by the general public in Bavaria as well as by the education ministries in the other German "Länder" (states). In fact, the document explicitly states that the cultural and economic contributions and achievements of Bavarians can be used as evidence that the educational policy compares favourably to any other German or European educational practice and policy.

The educational policy and curriculum in Germany is determined by each "Land". The federal government can make suggestions to all the educational ministries and in this way try to achieve a fairly uniform educational curriculum. As a consequence, students are able to move from one "Land" to another without too much disruption in their education sequence. The suggestions made by the federal government, however, do not have the force of law and do not have to be heeded by the "Länder". There are, in fact, ten different educational jurisdictions in Germany, each of which jealously guards its independence. Nevertheless, I am going to consider the Bavarian jurisdiction as representative of Germany.

The Canadian/Manitoba educational jurisdiction is similar to the German example in that Canadian educational policy is a provincial responsibility with little input from the federal government. Unlike Bavaria, Manitoba is barely one century old and has a very diverse cultural/ethnic population. According to a recent publication by the federal research branch about science education in Canada, there is great variability in science curricula across the country, more in the elementary grades than in the higher grades. This publication also claims that an international comparison study of science knowledge scores revealed that students in the western provinces had higher science achievement scores than eastern provinces. The very great differences in natural resources and economic activities from province to province leads to different curricula as each province tries to draft a relevant educational policy. I will consider Manitoba as a representative educational jurisdiction in Canada

There is, however, work in progress now to create a national, unified framework for science education for the whole country. This national effort is called the *Pan-Canadian Protocol for Collaboration on School Curriculum* and stresses the following components:

1. Understanding of the nature of science and technology and their relationship to each other and to society and the environment (STSE).

2. Skills for scientific and technological inquiry.

3. Knowledge and understandings of concepts in life science, physical science, and earth and life science.

4. Attitudes that support the responsible acquisition and application of scientific and technological knowledge to the mutual benefit of self, society and the environment.

This includes collaborative work and safety considerations and appreciation of the role of science in our lives.

The framework is intended for curriculum developers in the various jurisdictions who work within ministries and departments of education. It is, however, recognized that education is still a provincial or territorial respsonsibility. The purpose of the protocol is to increase the quality and the efficiency of curriculum development in Canada as well as to promote communication between curriculum developers among the provinces. The ultimate vision is to achieve scientific literacy across all provinces in Canada.

The document clearly states that what scientific literacy is, is hard to define, but a description of a scientifically literate person could be described as follows: A person is scientifically literate if he:

a) understands the nature of science and the scientific enterprise;

b) has knowledge of the major concepts, principles, laws, and theories of science and applies them in appropriate ways;

c) uses the processes of science in solving problems and making decisions;

d) understands the partnership of science and technology, and its interaction with society;

e) has developed science-related skills that enable him or her to function effectively in careers, leisure activities, and other roles;

f) has developed interests that lead to a richer and more satisfying life - one that includes science and life-long learning.

The Bavarian documents emphasizes the importance of students learning and using the vocabulary of science, appreciating and enjoying the solving of scientific-technical problems, and developing an intelligent attitude towards science and technology and recognizing the benefits of technical advances to society. They stress many of the same aspects of our description of scientific literacy but don't use the term or its equivalent in the German language.

Methodology

Rather than doing a global study of science curricula, I have chosen to compare the curricular guidelines and accompanying texts for the study of the central topic of heat and temperature in the two countries. In Bavaria this topic is part of the grade 9 curriculum while in Manitoba it is taught at the grade 8 level. There is, therefore, a significant age and maturity difference between students in the two countries that should be considered. These differences in age and maturity might be significant when we compare the placing of the concepts and the depth to which they are developed.

I will begin with a brief description of the historical development of the concepts of heat and temperature. This is important because of the recent findings that students' conceptual development generally replicates the actual historical development of the concepts in science.

This will be followed by an elaboration of the scientific concepts associated with heat and temperature as they are understood by todays scientific community.

Finally, a comprehensive literature review with emphasis on research findings about the preconceptions and conceptual development of students vis-a-vis heat and temperature will set the stage for the main part of this thesis.

I will then be ready to compare the curricula and the accompanying texts for the teaching of heat and temperature used in the two countries. From the curriculum documents I will also discuss the educational philosophy for the teaching of science in each country.

Finally, summarizing my findings, important implications for the middle years science classroom for the teaching of this important topic will be drawn.

The central part of my thesis can be considered a case study consisting of two parts: The first part will be a comparison of the curriculum guides currently being used in Germany/Bavaria and in Canada/Manitoba. I will outline the philosophy of science education taken from the introduction to each document and from the study of the curricular content itself. In order to elucidate this and to ease the comparison of the curricular content I have tabulated the concepts for each country on pages 41 and 42.

In the second part a comparison will be made between two widely used textbooks, one for each country, that have been prepared for use with each curriculum guide. The Bavarian text, ***Natur und Technik-Physik*** is intended for use by grade 9 Bavarian students and is written by Bavarian science educators. The Manitoba text, ***Science Dimensions 8*** is intended for use by grade 8 students in Manitoba and is written by Manitoba science educators, who are mostly practicing science teachers. A table of comparison of the textbook content is found on page 55 and 56. In the discussion and conclusions I will present answers to the guiding questions presented in chapter 1 and elaborate on some important implications for the science classroom.

Chapter 3 A Historical Account of the Development of Heat and Temperature Concepts

Fundamental Concepts of Heat, Temperature and Energy

The concepts of heat, temperature and energy have not always been understood in the same way as we understand them today. We expect to teach to our students concepts that were argued about by learned men of science over the course of several centuries. The well-known American physics educator Hewitt (1987), cited by Kesidou (1995), offers the following definitions that are used in the scientific community when talking about heat energy in general:

a) **Temperature** is the measure of the average kinetic energy of the molecules (particles) in a substance.

b) **Energy** which is transferred from one object to another because of a temperature difference, is called **heat**. When "heat flows" from one object to another it is **energy** that is being transferred.

c) **Internal** energy is the term used for the heat that has been transferred to another substance. Thus a substance does not contain heat, it contains **internal energy**.

d) **Potential** energy in a substance, due to the forces between atoms/ molecules and **kinetic energy**, due to the motion of the atoms/molecules are what constitute the **internal** energy of a substance.

e) The **quantity** of heat transferred by virtue of a temperature difference is measured by some (standard) change - such as the change in temperature of a known amount of water which absorbs the heat.

Heat is generally understood to be an **extensive** quantity, i.e. *mass dependent*, while temperature is an **intensive** quantity, i.e. *not mass* *dependent.* We can ask "how much heat?" but not "how much temperature?" For temperature we must ask "how high?" or "how low?"

These are roughly the definitions of the concepts of heat and temperature in today's scientific community. Clearly these are difficult and sophisticated concepts that we are trying to teach our students at the grade 8 level in Manitoba and the grade 9 level in Bavaria.

I think that some of these concepts are inappropriate for middle school children because of their abstract nature. It is, therefore, important to decide what kind of "intermediate concepts" might be suitably used in the students' conceptual development as they move to a reasonably complete and scientifically correct, understanding of these concepts.

The placing of this topic at these grade levels is interesting because in Germany the student age in a given grade is older than in Manitoba. This is due to the fact that in Germany a child must be a full five years old by the time s/he enters the school while in Manitoba a child has until the end of December to reach his/her fifth birthday. Another factor is that in some parts of Germany the school year begins near the end of July. This could mean that a grade 9 student in Germany would be about one and a half years older than a Manitoba student in grade 8. It would therefore be reasonable to expect the German student to be more ready for the study of formal concepts.

Extensive vs. Intensive Properties

According to researchers, cited by Keisidou et al. (1995), even eminent 17th century scientists did not clearly differentiate between heat and temperature, i.e. between **extensive** and **intensive** variables. Moreover, they had no concept of thermal equilibrium. Only in the late18th century, after Joseph Black's experiments led to a differentiation between the intensive and extensive heat variables, was the difference between heat and temperature finally clearly understood. However, heat was viewed as a "substance" that could be used over and over without ever being used up. Numerous scientists were involved in the shift from the substance/fluid (caloric) model of heat to the kinetic molecular model of heat. For example, Count Rumford used friction to produce an unlimited amount of heat with a blunt drill bit hat produced no metal shavings at all in his cannon boring machine. He made unsuccessful attempts to detect and measure the mass of any heat added to or removed from a given substance. Later, Sadi Carnot developed the entropy concept in 1824, and in the 1840's James Joule and Rudolf Clausius formulated the concept of kinetic energy of the molecules in a substance. These and other scientists struggled to develop a theory that could account for the observation that objects did not experience a mass change when heated or cooled.

Sensory Information

Man's interaction with fire and hot objects goes back thousands of years. The early interpretations given to these interactions relied solely on man's sense organs. When near a fire, an object becomes warm. Clearly "something" passes from the fire to the object. When we touch a hot object we experience the sensation of warmth. When we touch something cold we experiences the sensation of coldness. When one foot stands on a tiled floor and the other on a carpet lying on the same tile floor, one foot tells us that the floor is cold but the other that the carpet is warm. Correct interpretation, however, depends not only on the actual temperature measurement but on several other thermal properties of matter, properties such as heat conduction and heat capacity. These properties were not understood until the end of the18th century. Clearly, none of these properties could be properly understood until a method of quantifying heat using heat gains/losses and temperature was developed. An instrument that was not dependent on human senses had to be developed. This instrument was the thermometer. Roller (1957) cites Sir Humphrey Davy (circa 1810) saying:

> "nothing tends so much to the advancement of science as the application of a new instrument." p 119.

In order to elaborate on Davy's comment, it is instructive to give a brief account of the development of the thermometer to set the context in which the pioneers in the study of heat and temperature did their work , starting with Galileo and ending with Celsius.

Thermometer History

1) In 1592 Galileo devised a glass bulb with a long neck that was submerged in a vessel containing water. The water level in the stem rose and fell as the surrounding temperature fell and rose. A scale of sorts with no thought of standards, was attached to the stem for comparison. Sanctorius, a colleague of Galileo, did introduce standard marks, namely, exposure to snow and to a candle flame established the low and high mark. Unfortunately, unknown to them, changes in atmospheric pressure would also affect the water levels. His instrument was referred to as a thermoscope in 1617. In reality it was a "barothermoscope" since it reacted to changes in both atmospheric pressure and temperature.

2) In 1631 Jean Rey, a French physician, used a water filled glass bulb and a thin stem with an open end to estimate the temperatures of his patients. Temperature changes in the bulb cause the water to rise in the stem. This instrument eliminated atmospheric pressure effects but evaporation at the open end did affect readings.

3) In 1642 the Grand Duke Ferdinand II of Tuscany modified Rey's instrument and used alcohol instead of water and sealed the stem. This arrangement prevented any evaporation.

4) The Academia del Cimento (1657-1667) produced many variations of thermometers using marvelous glass blowing techniques (Appendix page 1&2). Standard points were:

a) the most severe winter cold.

b) the greatest summer heat.

5) In 1665 several "one fixed point" thermometers were developed. Robert Boyle used the freezing temperature of oil of aniseed. Robert Hooke used the freezing point of water. Christian Huygens used the freezing or the boiling point of water.

6) There were several scientists who used two fixed points for their thermometers: In 1669 Honoré Fabri introduced the use of two fixed points, the melting of snow and the greatest summer heat. In 1688 Dalencé used the melting of snow to represent -10 degrees and the melting point of water (ice) to represent +10 degrees for his two points. In 1694 Carlo Renaldini used the freezing and boiling point of water. These were called the "ice" point and the "steam" point.

7) In 1702 Olaf Roemer proposed that a certain mixture of salt and ice be made the lower fixed point and assigned a value of zero degrees and that the steam point of water be made the upper fixed point. This point was assigned the value of 60 degrees. It was after a visit to Roemer in 1708 that G.D. Fahrenheit in 1717 also proposed that a mixture of salt and ice be set as the zero for his scale. This temperature was thought to equal the coldest temperature of the winter of 1709. He hoped that this designation of zero would preclude ever having a negative reading for the

public. For his second fixed point Fahrenheit used his own body temperature. The distance between these two fixed points was then divided into 100 equal divisions or degrees. When this scale was extended beyond the body temperature, the freezing point of water became 32 degrees and the boiling point of water became 212 degrees. Thus, there were 180 degrees between the freezing and boiling points of water. He was also the first to use a cylindrical rather than a spherical bulb and mercury as the liquid.

8) In 1742 Anders Celsius used the freezing and boiling points of water as the fixed points and proposed that the distance between these points be divided into100 equal parts and that mercury be used as the liquid. At first he used zero degrees for the boiling point and 100 degrees for the freezing point. However, shortly thereafter, the scale was inverted so that zero degrees became the freezing point of water and 100 degrees became the boiling point of water.

Scientists now had an operational definition for temperature. Any objects that cause the mercury to rise to the same level were at the same temperature regardless of what human thermal sensory impressions suggested. For example, if a shovel is left outside overnight, the wooden handle on a shovel and the steel shovel itself can be shown to be at the same temperature even if the steel feels much colder than the wood. But when measured with a thermometer, both parts would cause the liquid to reach the same point on the scale.

Thermal Equilibrium

The thermometer had been developed by the beginning of the 18th century and an entirely new science, that of *heat measurement*, developed. Now it was possible to determine accurately and precisely that all objects, no matter what their initial temperature may have been, and no matter what substance they are made of, when placed into a room without fire and into which the sun does not shine, all end up at the same temperature. One of the first to use a thermometer to measure temperatures with precision was Joseph Black (1728-1799). Although Black conducted many of his own experiments, he also considered and evaluated the work of many other researchers and adopted some of their procedures for his own experiments. It was Black who studied the *state of heat equilibrium* that existed between objects in a room. The redistribution of heat between the objects in a room was interpreted in different ways. Hermann Boerhaave (1668-1738), a teacher of medicine at the University of Leiden, and Pieter van Muschenbroeck (1692-1761), a professor of philosophy, believed that, when heat equilibrium was attained, every cubic inch of space in the room, held the same amount of heat. Thus one cubic inch of air held the same amount of heat as a cubic inch of wood or of stone or of iron etc. However, to Black this concept of heat equilibrium meant that there was no longer any heat flowing between the objects. According to Black, heat was something that flowed between the objects, from hotter to colder, while the temperatures were observed with a thermometer. He was one of the first researchers to clearly differentiate between the quantity of heat and the intensity of heat.

Specific Heat

The idea that equal volumes of substances at the same temperature contain the same amount of heat was tested by Fahrenheit who mixed a volume of water at 100 °F with a volume of water at 150 °F and found that the mixture attained, as expected, an average temperature of 125 °F. The cold water gained the same "number of degrees" as the hot water lost.

Stated another way, the heat gained by the cold water equalled the heat lost by the hot water. However, when an equal volume of hot mercury was used in place of the hot water, mercury having a density approximately 13 times that of water, the final temperature was 120 °F even though the heat lost by the hot mercury equalled the heat gained by the cold water. Black concluded that equal quantities of heat would heat mercury more than an equal volume of water. Two assumptions that are involved are:

a) heat is neither created nor destroyed during mixing, i.e. heat is conserved,

b) account must be taken of any heat gained from or lost to the surroundings.

Heat was considered to be an imponderable, massless material substance having many of the properties of ordinary matter including the early historical idea of conservation of mass.

The heat to volume relationship in mixtures proved to work only if the same substance was used for both hot and cold portions. Black concluded that equal weights of matter at the same temperature had equal amounts of heat, i.e. the quantity of heat in a substance was proportional to its weight. However, when equal weights of cold water and hot mercury were mixed, the final temperature was not the middle temperature. The mercury's temperature change was much larger than expected. Since the same quantity of heat produced a much larger temperature change in mercury than in water Black inferred that the mercury had a much smaller *capacity* for heat than the water. The concept of heat capacity was first tested by George Martine (1702-1741) who used equal heat sources from a fire to measure the heating rate of equal volumes of different substances placed in identical containers before the fire. He found that mercury warmed up at a rate about twice that of water even though each substance acquired heat at the same rate from the fire. These results were similar to those of Fahrenheit and later extended by Black. In another experiment Martine found that when heated to the same high temperature and then exposed to the same cold air, assuming that both containers lost heat at the same rate, the mercury also cooled off at about twice the rate that the water cooled.

Black used Martine's method of constant heat supply to determine that a given substance's rise in temperature (heat gain) was directly proportional to both the mass of the substance and the change in temperature. However, to form an equality, an unknown factor was needed. This factor, variously referred to as "affinity for heat" or "faculty for receiving heat" or "appetite for heat" and finally "capacity for heat" is now called "heat capacity". Heat capacity was found to be substance specific. Richard Kirwan, a contemporary of Black, was the first to suggest that the heat capacity of water be taken as a standard, a practice we still employ today.

After perfecting the technique of measuring heat capacity Black was also able to determine the heat of fusion and the heat of vaporization of various substances. The heat of fusion refers to the heat that must be added to ice to melt it even though the temperature does not rise. The heat of vaporization refers to the heat that must be added to evaporate a liquid even though the temperature does not rise. The question that still had not been answered was, "What exactly is "heat"?" As early as the beginning of the 17th century, Francis Bacon observed that:

a) when soft iron was repeatedly struck with a hammer it became red hot

b) friction produced heat

c) flint struck upon steel produced sparks.

From these observations he came to the conclusion that heat involves motion. Two schools of thought thus came into being. Most of the English philosophers supposed that the particles of the matter itself had some kind of motion. The French and German philosophers, on the other hand, contended that this motion was in the particles of a subtle, highly elastic, and penetrating fluid matter that is contained in the spaces between the particles of a heated body.

Caloric Theory

What are the properties of this "substance" that seems to be involved when substances are heated and cooled? Lavoisier called it "caloric" (1787). Since heat was considered to be a material substance, i.e. matter, it needed to have its properties or assumed properties defined.

1) Caloric is an elastic fluid whose particles repel each other.

2) Caloric particles are attracted to other particles with the magnitude of this attraction different for different particles.

3) Caloric cannot be created nor destroyed.

4) Caloric can be sensible, i.e. increases the body temperature when added, or latent i.e. combined with the body's particles similar to a chemical combination to produce a new substance - the vapor or the liquid.

5) Caloric does not have a measurable mass.

The Caloric Theory states that when a substance is heated, caloric moves into the substance and occupies the spaces between the particles which compose the substance. The more caloric in the substance, the hotter it is. When an object cools off, it is losing caloric. A consequence of caloric occupying the spaces between the particles of a substance is that the substance expands, i.e. the volume increases, when the object is heated and contracts, i.e. the volume decreases, when the object cools. The seeming masslessness of caloric presented no problem as long as sensitive balances were not available. It was a useful theory, but there were some things that could not be explained by it. For example, why do two objects that are rubbed together both get warmer? Where does this caloric come from? Why does water expand in volume when cooled below 4 °C to 0 °C and decrease in volume when warmed over this temperature range? If caloric is removed from a substance the volume should steadily become less. This anomalous behavior of water was reported by Count Rumford in 1797 and cast doubt on the validity of the caloric theory.

It is well accepted that experiments cannot ever prove a theory to be correct beyond the shadow of a doubt but sometimes an experiment can disprove a theory. Since caloric was considered to be matter, it had to be attracted gravitationally. Count Rumford (Benjamin Thompson) (1753-1814), set out an extensive research program to study the mass aspect of heat. Contrary to the majority opinion of the day, Rumford considered the doctrine of heat as a form of motion to be more sound and more useful. After years of work, during which he perfected both the apparatus and the necessary technique, he concluded that heat added to a body does not increase the mass of the body.

Rumford then turned his attention to the postulate that heat is a material substance. If the postulate that heat is a material substance were true, the law of conservation of mass, namely that mass cannot be created nor destroyed, should apply. Being in charge of cannon boring for the military in Munich, Germany, Rumford noticed, (1797), the large amount of heat that was generated during the boring process. Supporters of the caloric theory gave several possible explanations to protect their theory:

a) the specific heat, i.e. the heat needed to change the temperature of 1 g of metal by 1 °C, of the metal changed (decreased) drastically when the turnings were separated from the bulk metal.

b) the pressure of the drill upon the bulk metal squeezed the latent heat out of the metal much as soft iron becomes very hot when hammered.

Rumford challenged the caloric fluid theory and found that there was no change in the specific heat of the metal turnings. The next explanation was more difficult either to verify or to falsify. Rumford used water to measure the amount of heat produced. Boxing the site where the dull drill bit was rubbing the cannon and filling the box with water and carefully measuring the temperature change of the water, he was able to quantify the amount of heat produced. He discovered that the amount of heat produced in this manner seemed to "be without limit". This observation went against the so-called "principle of conservation of caloric". He argued that if heat can be created in this manner "without limit" then heat cannot be a material substance. Like Boyle, a hundred years earlier, he concluded that it must have been motion that was communicated to the particles during the boring process.

The publication of his experimental results helped to convince some in the scientific community that the caloric theory was not as useful as the motion theory. Rumford was a central figure in the process that led to the demise of the caloric theory. The motion theory, first postulated by Francis Bacon in 1620, gained followers even though it was not at all clear what type of motion was involved except that motion was often involved in the generation of the heat.

The suggestion by Sir Francis Bacon that heat involved a kind of motion and the ideas of Robert Boyle culminated in the conclusions that

Rumford arrived at through his carefully conducted experiments. The caloric theory, useful as it had been, was not the most appropriate explanation for understanding heat and temperature. Consequently, it was discarded by all scientists, but the paradigm shift took almost a century. Unfortunately, textbooks implicitly or explicitly suggest that such major changes in theoretical orientation occur quickly and decisively within a few years. The story of this important change in our thinking about the central concepts of heat and temperature should be told in the classroom.

Chapter 4. Literature Review

A search of the literature shows that a great deal of research has been recently done in the field of the teaching of heat and temperature to children. The role played by childrens' conceptions when they enter the classroom to learn about heat and temperature has also been widely studied. Unfortunately, science teachers are generally unaware of this recent research.

Osborne (1984), talks about "mini-theories" held by children as well as by adults. These are the conceptions developed by a person through experience or formal instruction. In relation to the topic of dynamics in physics, he identifies threes levels of "mini-theories":

1) gut dynamics 2) lay dynamics 3) physicists' dynamics

Gut dynamics are those mini-theories or conceptions developed from experience alone - unarticulated and are often held by children without being aware of them. They may be contradictory but present no threat to the person who considers them as single entities and not as part of a unified set of conceptions. Lay dynamics are those conceptions developed from the language-based experiences in a social context which includes people, books and other media. Physicists' conceptions are those that are deliberately articulated in linguistic and mathematical terms to form a highly coherent set of ideas.

The same kind of progression in the development of conceptions about heat can be seen in the work of other researches. In a study of the development of the conception of heat in children, Albert (1978) used an approach similar to that of Piaget to study the development of a group of concepts involving the terms "hot", "warm", "heat" and "temperature". She found that even at a very early age (two year old) children have a conception of "hot" based on purely sensory impressions. Thomas et al. (1993), reports on the teaching of heat and temperature to university science students in Portugal. Although thermometry is first taught at the grade nine level, the researchers discovered that university students had much the same ideas about heat as those held by the grade 9 children before any formal teaching had taken place. Adults, whose formal science education had ceased at the grade 9 level, were also found to hold the same heat-related ideas as these children. Students generally believe that different sensations mean different temperatures. When students experience the sensation of a tile floor on their feet and then a carpet on the same floor, they get the idea that heat is a property of the substance itself. The key concept of thermal equilibrium, taken for granted by teachers and by textbook writers, is not present in the majority of students. Students think that some substances are naturally colder than others because of the materials that they are made of. They also consider the object and its temperature to be a unified whole. The object is not considered to be something to which heat can be added. e.g. "X" (an object) is hot, "X" makes me feel hot. The sun is hot. Ice is cold. For most students, temperature is a property of the material that the body is made of and is also a measure of heat.

Watson and Konecek, cited by Kesidou et al. (1995), had students place thermometers in rolled-up sweaters and hats and a rolled-up rug and then asked them to predict how these readings would compare to outside readings. The students expected a higher temperature in the sweaters because their experience was that sweaters "give heat" or "are warm". Surprisingly, the unexpected results did not convince the students that their alternative frameworks were wrong. Instead, they rationalized that a longer time was needed or that cold, outside air had come in. Their original ideas are described by various researchers as "highly robust", Duit (1981), Erickson (1979), Viennot (1979) cited by Solomon (1983). Duit writes that these other notions, alternative conceptions,

> "generally live on under a thin layer of physical knowledge", p. 299 .

Indeed, Solomon expresses surprise that researchers are worried that means need to be found to extinguish these alternative frameworks. She claims that, what she calls "socialized knowledge", can, by its very nature, never be extinguished.

Albert (1978), found that five to six year-olds begin to give the hot bodies the ability to "make me hot". e.g. "The sun makes me hot." "The oven makes me hot." The hot objects seem to become active. The objects become sources of heat which can cause other objects to become warm/hot. At this age the children also become aware of the fact that there is something they can do to create or remove heat or hotness. They can switch the oven on and off just like a light can be turned on or off and instantly produce light/hotness. Thus, there emerges an awareness of the control that the child has over whether or not a body is hot/warm.

By age seven children become aware of the fact that time is involved and the instant nature of hot and cold does not really exist. "The sun warms it up." The sun is seen to work upon an object to warm it up over a period of time, and not instantly. Heating water in a container is also seen to take time. Heating an object has now become a process.

By age eight or nine the children clearly distinguish between hot and warm. Hot results in a burn while warm is comfortable or "feeling nice". They also relate to different personal reactions to hot and warm. "If you put your fingers in a candle flame real quick you don't get burned." Children also become aware that heat can be produced by objects that by themselves are not hot, but that certain actions are necessary in order to maintain the production of heat. They say, "You have to plug it in." At this age the children also begin to use the concept of "degrees." An oven at 400 degrees is hotter than an oven at 200 degrees.

The addition of "degrees" to the students' vocabulary is not without its own problems. Many students, equating heat with temperature, use the additive method to solve problems. Stavy and Berkovitz (1980), found that students readily predicted the correct outcome when two cups of cold water poured together. However, when a cup of 20 °C water is mixed with a cup of 10 °C water, some students predicted that the final temperature would be 30 °C while others predicted 10 °C. The basic arithmetic process of addition is used.

Another researcher, Erickson (1979), studying the substantive aspects of 12 year old children's thinking about heat and temperature, noted that the children could be expected to have considerable experience with situations involving heat and temperature. These childhood experiences form the basis for their beliefs about heat and temperature. However, in their minds, there is no real distinction between heat and temperature. Students view heat and temperature as synonyms that can be used interchangeably.

Children seem to perceive heat as a material substance with properties attributable to matter. Heat can be added to or removed from a substance to make it hotter or colder. Erickson (1979), calls this the "caloric model". Shayer and Wylam (1981), found that conduction was usually treated in terms of a "heat-fluid" caloric model. Metals heat up faster than wood because they attract heat better. Erickson (1979), also found that students use terms like "fumes" or "gases" or "bubbles" to describe heat. "Heat rises" is a common expression used. When ice cubes melt they lose their coldness. They view cold as the opposite of heat. Objects become cold because they gain coldness or that the heat escapes as fumes or as a gas or as hot air.

In order to present a summary picture of the sequence of childrens' conceptions I have set up the following table. I used research by Albert (1978), Erickson (1979 and 1980), and Hewson (1984), to show at a glance the complexity of what a teacher has to deal with in the teaching of heat and temperature. We see the gradually changing conceptions mentioned by Posner et al. (1982), as the child gets older. The "age-determined progression" mentioned by Albert (1978), is also clearly evident.

Age-Dependent Conceptions of Heat

age (a)	conceptions	verbalization
Albert (1978)		
2-3	heat = hot object	"Stove - hot."
4-6	-An object is hot. -Personal source of heat. -Objects can be made to produce heat - on switch. -Hotness is a condition that an object can be in or not.	"The sun makes me feel hot."
5-6	Hot objects can heat other objects i.e. source of hotness and directional movement. -The sun is an active agent.	"The sun makes the outside hot."
7-8	Hotness has a conditional nature, i.e. can be turned on and off. Personal activity produces heat.	"If you turn the oven on you can feel the heat." "When you run fast and don't stop you get hot."
	Becoming hot is a process that takes time.	"The sun warms the air up and then it becomes hot."
	Cold, warm and hot are a single dimension, i.e. a continuum.	"Like hot is sort of burn you and warm is feeling nice." "When you touch a hot object like a flame, quickly you don't get burned; if you touch it slowly you will.
8	Heat and object are differentiated. Heat is localized and controllable. Heat is an entity.	"Heat rises." "You can turn the stove on and get heat."
8-10	Degrees of heat - numbers.	"The air is 33 degrees." "200 degrees is hotter than 100 degrees."
	Physical objects can produce heat.	"... motors in cars that were driven a lot are hot"
Erickson (1979 and 1980)		
12	Heat is fumes that rise. Two forms of heat hot heat and cold heat. Heat can be added or removed. Temperature is related to object size. Temperature of mixtures is additive.	

Hewson (1984), in Sotho, S. Africa.			
15 & 34	People are hot because of:	- travel - waiting - tiredness - gave birth	- are pregnant - anger - sickness - sadness
	Physically observable phenomena of heat: - burning - melting - boiling - rising hot air		

The concept of thermal equilibrium is now generally accepted and used without question by teachers and textbook writers. It is expected that students will immediately see the logic of this concept. Teachers expect students to view cooling and heating of substances as thermal interaction processes, but many students do not make this connection. The formal definition of heat is given in terms of thermal equilibrium, a concept not automatically used by students. Heat is thought of as the energy that flows from the hotter to the colder substance until thermal equilibrium is reached. Therefore, according to Thomas et al. (1993),

> ". . . this implies that, in order to reach the scientific meaning of heat and temperature, students must understand correctly what is meant by thermal equilibrium." p.21.

Since childrens' alternative conceptions are so strongly rooted, Kesidou et al. (1995), believe that challenging demonstrations are called for in order to alter the students' views, and that thermal interaction and thermal equilibrium are key concepts in students' understanding of the scientific view of heat.

We should not forget that teachers and students often view the same phenomenon from very different perspectives. The student approaches the study of heat and temperature from the perspective of experience as described in everyday language which often has a variety of terms that are used to talk about or to describe the same phenomenon. Solomon (1983), citing Viennot (1979), and Duit (1981), claims that these everyday explanations are deeply rooted in the child's everyday world. Student conversations and the mass media daily confront the student with implicit assumptions about how things operate and what properties they have. She calls it "being socialized" into a world of non-scientific explanations.

Another variable that seems to confound the students when dealing with simple heat exchange equations is the mass of the substance. What is the relationship between mass and the amount of heat being exchanged? Some students believe that if the temperature is the same, then the amount of heat must be the same. Clearly, for many student temperature is an extensive quantity and not an intensive property. An alternative idea relating to ice cubes is that it takes longer for a large ice cube to melt because it has a colder temperature than a smaller ice cube.

Erickson (1979), contends that by knowing what the students' conceptions are, the teacher gains an understanding of the difficulties experienced by the students. The teacher can then devise suitable teaching strategies to facilitate the students' conceptual development and growth.

The conceptions that the children have when they get to the classroom have been developing long before there was any teacher mediation in their learning. Erickson (1979), refers to the famous quote by Ausubel:

> "If I had to reduce all of educational psychology to just one principle, I would say this: The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly." p. 221

Wiser also concludes that guiding students from their everyday conceptions to accepted scientific conceptions is always a difficult and lengthy process. Even the provision of experiences designed to lead the student to scientific concepts may not be enough. If the interpretation is not done adequately, the experiences will not be enough to convince the student that their alternative frameworks are inadequate. Linn and Songer, cited by Arnold et al. (1996), found that after a 13 week "thermodynamics" curriculum study at the grade 8 level, students did differentiate between heat and temperature and did understand the variables influencing heating and cooling. Unfortunately, only a few students generalized their understanding to naturally occurring phenomena. Most maintained that these phenomena were governed by other principles. Perhaps the students see the need to accept and accumulate the scientific view for classroom work but don't see the need of scientific explanations in the context of everyday experiences.

As mentioned earlier, the students come to the science class with a set of ideas and explanations that have served them satisfactorily for years. Natural phenomena can be understood and explained with little cognitive conflict. For many teachers, the childrens' views are largely unknown but indications are that they have a major impact on the childrens' subsequent learning (Freyberg and Osborne 1980). They have developed an understanding for the same words used by the teacher, who uses them in his/her teaching in a scientific sense but then interpret them in the everyday sense (Freyberg and Osborne 1980). This mismatch of vocabulary interpretation is a barrier to learning the scientific concepts.

It is now widely accepted that the alternative frameworks seem to be "highly robust" (Posner et al. 1982) and particularly resistant to change.

Often they are influenced in unaniticipated ways by science teaching (Freyberg et al. 1980) The mismatch of vocabulary interpretation is one of these unanticipated ways. Students also either reject the ideas that don't fit with their views or distort them in such a way that they do fit their alternative frameworks in a, to them, satisfactory fashion.

Such a wide variety of ideas, understandings, alternative conceptions etc. with which the children enter the classroom make the task of the teacher very difficult. How is the teacher to take the students, all of them, from where they are, conceptually, and bring them to a point of view or understanding consistent with the scientific view? How can the common-sense or "phenomenological concept ecology" (Posner1982) be brought in line with accepted scientific concepts? Are there certain teaching strategies which can be utilized to bring about conceptual change? What is involved in successful conceptual change?

Middle school students are at different levels of development, from early concrete to early formal (Shayer and Wylam 1981). Considering temperature as an intensive property seems to be beyond many of them. Early formal students seem to have acquired an interest in **how** heat causes its effects. Heat has become an extensive property. They realize that a spade left outdoors overnight is all one temperature even though the wooden handle does not feel as cold as the metal blade. However, most students in the 11 to 13 year-olds use the "heat fluid" model for conduction instead of the kinetic theory model of particle movement.

This diversity of entry levels to the understanding heat and temperature in students makes it all the more important to discover where the students are and to start the instruction from that point. The aim of the instruction is to bring the student's understanding in line with scientific ways of thinking, that is, to change the preconceptions of heat and temperature held by the students. These conceptions are, according to Posner et al. (1982), "highly robust". Hewson et al. (1989), refers to the rich, pervasive, contrary and stubborn nature of learners' ideas. However, conceptual change can be brought about if certain conditions exist. According to Posner et al. (1982), a new concept under consideration by a student must be:

1) intelligible, 2) plausible, 3) fruitful.

If these three conditions are met, the status of the new concept will be raised in the mind of the student. A fourth condition that must be met if a long held conception is to be exchanged for a new one is that the status of the original conception must be lowered. There must arise, in the mind of the student, a dissatisfaction with the old conception, i.e., he old conception must become less useful. The new concept must prove to be more fruitful in the explanation of new and diverse phenomena.

When a student encounters a new concept, s/he is faced with the problem of integrating it within the concepts already held, i.e. his/her "concept ecology" Posner et al. (1982). The new concept may simply be added to the existing concepts if there is no conflict, or it may have to replace (an) existing concept(s) or existing concepts may simply have to be modified. Rowell et al. (1990), conclude that for optimal rate of progress in overcoming a conception that is false or even just limited, students should first construct another potentially relevant, perhaps even contradictory, better explanation. This explanation should be firmly based on the students' "knowledge structure".

A complementary view of learning science is proposed by Glynn and Duit (1995). They talk of "constructive learning of science" They believe that five conditions must be met in order for a student to learn science meaningfully:

1) Existing knowledge is activated.
2) Existing knowledge is related to educational experience.
3) Intrinsic motivation is constructed.
4) New knowledge is constructed.
5) New knowledge is applied, evaluated and revised.

The "constructive" position is that the existing ideas held by the students are in a state of flux and not solidly set, finished and immovable. These ideas are good until better ideas and explanations are presented to account for and to explain new phenomena. A differentiation is made between "conceptual models" and "mental models". Conceptual models are the tools for the understanding and teaching of physical systems while the "mental models" are what people actually have in their heads. The teacher's job is to activate the existing mental models and to have the students reflect on them. According to Glynn et al. (1995), effective science teaching must by guided discovery learning in which the students are provided with intriguing questions, baffling situations or interesting problems which require the students to make observations, form hypotheses and test solutions.

The constructive learning model holds that the student learns by constructing conceptual models by relating new experiences to existing knowledge/conceptions . Thus the mental models of the student are in a constant state of change as new experiences are integrated with existing knowledge in a relational way instead of rote learning. The student constructs meaning of related concepts and his/her existing knowledge but not memorizing lists of unrelated facts. This, of course, results in no two students having exactly the same mental model even after participating in the same experience since each student has his/her own set of preconceptions. The formation of relational conceptions that develop over time activates long-term memory. The alternative, rote memorization of facts, leads to short-term, useless knowledge acquisition and poor attitudes about learning science.

As mentioned earlier, Solomon (1983), claims that the alternative frameworks or socialized knowledge can never be extinguished. Glynn et al. (1995), agree and contend that mental models are continually reinforced by the students' social contexts and are thus not forgotten. It is therefore:

> "unrealistic for teachers to expect students to eliminate their mental models, replacing them with conceptual models learned at school. What is realistic is to expect students to activate the appropriate model in the appropriate context - this is a reasonable and attainable goal of science instruction." p. 21.

Other researchers mention the robustness of these conceptions and the students' tendencies to return to them in spite of formal teaching of the scientific concepts. How can this problem be solved? Solomon (1983), suggests that students not be required to extinguish ideas such as "wool is warm" but rather they should be taught the scientific explanations and then be able to think and operate in the two, coexisting spheres - everyday notions and scientific explanations - and to be able to distinguish between them.

Along the same lines, Duit (1987), argues the usefulness of considering (heat) energy as a "quasi-material", i.e. as something concrete even though, in the physical sense, it is not a substance. The usefulness of this position lies in the fact that it is readily understandable to the student and serves as a bridge until such a time when the student is ready for the scientific explanation. Stinner (1995), emphasizes the necessity to go softly on trying to extinguish the notion of heat as a material substance that can be transferred from object to object.

> "Our goal then is to postpone the full, decontextualized imparting of organized science content, or "scientists' science" until the students are able to demonstrate a readiness for it." p.561.

Duit (1989), says,

> " Yet in classical physics (including special relativity theory), the quasi-material notion is to a large extent compatible with the abstract energy concept, provided its limitations are taken into account." p.142.

The mental model of heat as a material substance is more understandable to students than the model of heat as energy because it is simpler to connect with other conceptions. According to Glynn et al. (1995), teachers introduce students to conceptual models in order to simplify complex natural phenomena, and making the phenomena more understandable to students. The use of the caloric theory seems to achieve this purpose.

Summary

Children learn about heat and temperature from a wide variety of sources both social and from their own sensory perceptions. The complexity of their conceptions of heat change as they grow and develop mentally. These ideas are strongly rooted in their minds and difficult to dislodge and to change. The differentiation, by students, between heat and temperature is not natural. Rather, the terms are used interchangeably.

Moreover, the notion of thermal equilibrium is not automatically arrived at by children. It must be clearly taught using suitable teaching strategies.

However, even the best lesson plans do not guarantee that the students will learn what the teacher is teaching. The students process the provided activities and information against a "backdrop" of their own conceptual ecology. This results in various accommodations being made for the new concepts. The vocabulary used by the teacher may be understood by the student in totally different ways than what the teacher intended. Therefore, it is vital that the teacher know something about the "preconceptions" that the students have about the topic of heat and temperature.

Considering that a student's conceptions are in a constant state of flux, becoming more and more sophisticated and detailed, it seems useful to use some intermediate "quasi-real" concepts like the caloric theory to bridge the gap between the concrete and the formal stage of student mental development. Duit (1987), maintains that,

> " The abstract energy concept cannot be grasped by these relatively young students. Concrete notions are necessary, and quasi-material conceptions would seem appropriate." p. 145.

The robustness of the students' original conceptions, which are based on a mainly social context, make it imperative that the students be made aware of the scientific context and the social context in which phenomena are observed and discussed. The students must be made aware of the fact that the context in which a phenomenon is considered, determines the choice of vocabulary. Additionally, the student must come to see that the scientific explanations are more fruitful than their own socially developed conceptions.

A competing position to conceptual change, taken by some writers, holds that childrens' preconceptions can never be totally extinguished even when compelling reasons exist to change them. Teachers, they argue, then need not be too concerned about totally replacing inadequate preconceptions but must make students aware of the contexts in which concepts are being considered so that they use the appropriate language. An example of this is the caloric theory which, historically, was accepted and used quite satisfactorily during the time when the current kinetic model of heat was being developed by the scientists of that time. In the same way, I will argue, the caloric theory can be used by students now as they strive to come to an understanding of heat and temperature.

Chapter 5. Comparison of the Curriculum Materials for the Teaching of Heat and Temperature in Germany/Bavaria and Canada/Manitoba

The German/Bavarian curriculum guide is dated 1993 and the Canadian/Manitoba curriculum guide is dated 1991. Both are currently (1998) in use as the official documents for the respective school jurisdictions.

The curriculum guide and its rationale provide a glimpse into the philosophy of those who are responsible for the development of the curriculum for a given subject. Whether or not this philosophy is in fact adopted by the teachers who deliver the instruction is another matter. The official philosophy outlines the goal or desired outcomes that the education authorities want the students to attain. Several questions immediately come to mind at this stage:

1. Is there a significant difference between the philosophies in Germany and in Manitoba?

2. To what extent do teachers follow the philosophy espoused by the curriculum writers?

The German curriculum guide for grade 9 science includes a section on Heat and Temperature. About 42 hours of instruction are recommended for this topic. Since each class is 45 minutes in length this works out to 56 periods of instruction. At the grade 9 level there are three periods of instruction per week so that 19 weeks are recommended for the teaching of heat and temperature.

The introduction to the curricular details emphasizes that the students must consider everyday manifestations of heat and temperature events. It is emphasized that, in order to understand and to explain these events, the particle model of matter can be successfully applied. Students are to use the gas laws that are experimentally demonstrated, and derive the Ideal Gas Law ($PV = nRT$).

The purpose for acquiring this knowledge is said to be to enable the student to understand the role played by heat and temperature in their environment as well as in technical applications. In addition to these considerations and understandings, the student is to learn that the operation of "heat machines" such as steam turbines, internal combustion and diesel engines, do affect the environment and that these effects can be quantitatively measured and evaluated.

The details of the curriculum for the Bavarian students at the grade 9 level are divided into seven main topics. They are outline in the next section.

Curriculum Content * Germany/Bavaria

1. **temperature; heat; internal energy;**
   - temperature measurement (Celsius)
   - temperature as a measure of average kinetic energy of particles (Kelvin)
   - temperature changes vs. volume changes
   - heat as transfer of energy from body to body
   - internal energy as stored energy
   - changes in internal energy due to addition of work or of heat
   - changes of state as a consequence of change in internal energy
2. **heat movement**
   - conduction in solids, liquids and gases
   - radiation
   - convection
3. **behavior of bodies during temperature change**
   - length - coefficient of expansion
   - volume - coefficient of volume expansion
     - solids and liquids
   - anomalous volume behavior of water
4. **temperature, pressure, and volume of a confined gas**
   - pressure vs. volume at constant temperature (Boyle's Law)
   - temperature vs. volume at constant pressure (Gay-Lussac's Law)
   - Kelvin temperatures
   - general gas law
5. **law of heat exchange**
   - law of heat exchange
   - specific heat capacity
   - temperature of mixtures
6. **changes of state**
   - melting and freezing temperatures
     - heat of fusion
     - pressure effect on melting temperature
     - freezing point of solutions
     - volume changes during melting and freezing
   - evaporation and condensation
     - boiling point
     - heat of evaporation
     - pressure effect on the boiling point of water
7. **first law of thermodynamics (conservation of energy)**
   - work of expansion of gases
   - structure and function of heat machines
     eg. steam turbines, Diesel and internal combustion engines
   - types of environmental interactions
   - measurement of environmental effects

* From the 1993 curriculum guide
CARL-LINK-VORSCHRIFTENSAMMLUNG

Curiculum Description: Canada/Manitoba

The publication *Science Education in Canada,* Volume I, (1985) described the science curriculum in Manitoba as "in a state of flux" during the late 1970's. The 1976 interim guidelines recommended the inclusion of "core" and "optional" topics. A base of objectives and learning activities designed and selected by Manitobans accompanied these topics. Middle school students were to spend 60-70% of their science time on the "core" topics. This local control over the optional topics gave flexibility and allowed the teacher to more closely match the topics to the local situations. However, province-wide assessment for grades 5, 8 and 11 were implemented to provide a broad base of accurate information about student performance.

The goals of schooling are described in this document as being much the same in all provinces. There is, however, a shift in emphasis as the student moves from the elementary level to the upper secondary levels. The shift is from the development of generic skills and base knowledge to the application of these skills and knowledge in specific subjects and contexts taken from a focus on family and the local community to wider communities.

The Manitoba curriculum was described as activity based (p.142). Such a curriculum lists objectives, content and activities with no specific text in mind. The current curriculum, on the other hand, (1991), is based on a specific text written and produced by Manitoba science teachers and educators.

The Manitoba curriculum places the study of heat at the grade 8 level. About 22 hours of instruction are suggested for this topic. Each science class is 45 minutes long so that about 30 periods are to be devoted to this topic. Since science is taught every day, this is a five week study.

The rationale for the inclusion of heat study in the curriculum is simply given as:

> "Heat is a form of energy which can be transformed from other energy sources. Students will observe how heat is transferred by conduction, convection and radiation. The home heating system is composed of technological devices. There are alternatives to the use of fossil fuels for heat production."

Curriculum Content: ** Canada/Manitoba

1. Heat is a form of energy
2. Heat is a measure of the total energy.
   - -depends on temperature, mass and composition of matter

   Temperature is a measure of the average kinetic energy.
3. Heat can be transformed from other forms of energy.
   - a) friction b) percussion c) compression
   - d) dissolving a solute e) electric current
4. Heat can be transferred.
   - a) conduction b) convection c) convection
5. Heat causes expansion and contraction.
   - a) in solids b) in liquids c) in gases
6. Different metals expand at different rates.
   - a) bimetallic strip b) applications - gaps in construction units
7. Alternatives to fossil fuels.
   - a) heat pumps b) solar energy c) electricity

**From the 1991 Science: Grade 8 guide
Manitoba Education and Training

Curriculum Comparison:

A comparison of the Bavarian and the Manitoba curriculum content quickly shows that the Bavarian curriculum writers include much more detail and more sophisticated concepts than the Manitoba curriculum writers. However, it must be remembered that the time recommendation in Manitoba is about half that of Bavaria and that the students in Manitoba are younger.

The following is a list of topics included in the Bavarian curriculum and not even mentioned or alluded to in the Manitoba document.

- internal energy
- law of heat exchange
- specific heat capacity
- heat of fusion
- heat of evaporation (vaporization)
- pressure effects on melting and boiling points
- freezing points of solutions
- work of expansion
- environmental effects
- heat machines

The Bavarian curriculum also contains a lot of quantitative concepts. Most of them can be incorporated into experiments and the measurements used to calculate each concept value. The topics are:

- coefficient of length and volume expansion
- specific heat capacity
- heat of fusion
- Kelvin temperatures

The Bavarian curriculum lists the following gas laws which are to be treated in a quantitative manner:

- Boyle's Law
- Gay-Lussac's Law

In contrast, the Manitoba curriculum is primarily qualitative in nature. Thus it is far less demanding. The great difference in time allottment is, perhaps, one of the reasons for this. However, the fact that the Manitoba students could be as much as a year and a half younger than the German students is probably a more important reason for the lower expectation. None of the gas laws are mentioned by name. The concepts listed are treated in a very general manner with no emphasis on the characteristic effects of heat on different substances except for the fact that different metals have different expansion rates. The behavior of a bimetallic strip is to be demonstrated and its application in a thermostat is suggested as a way to show the connection between science and technology.

Role of Teacher Demonstration and Student Experimentation

Another aspect of any science instruction is the role of teacher demonstration and student experimentation. In this regard, the German preamble to physics instruction places a high value on experimental activities. It is emphasized that student experiments play a central role in the development of scientific thinking and in the construction of scientific models. The students are to learn how to plan, carry out, describe and evaluate the results of their experiments in order to develop a readiness for disciplined co-operation with their fellow students and to develop a constant awareness of safe laboratory behavior. The development of manual dexterity and increased interest and enjoyment of scientific-technical problem solving are seen to be other valuable outcomes of the experimental aspect of science. This is the official philosophy explicitly stated in the curriculum document. However, the classroom practice is often quite different. Long standing practice and the cost of science equipment has resulted in many schools being equipped mainly for teacher demonstration and not for student participation, Henderson(1992).

Personal Observations

When I looked around in the science room in which I taught during my year in Germany, I noticed that there was no scientific apparatus in the classroom at all. The storeroom had one triple-beam balance for the whole chemistry department. The science budget for that year, 1982-'83, was 600 DM, equivalent to $300 CDN. The school I'm talking about is a "Gymnasium" i.e. a high school that prepares students for entrance to a university. Unfortunately, I did not have opportunity to observe another teacher at work and can therefore not comment on actual practice. However, this lack of equipment does suggest that student participation in lab activities is not common and that teacher demonstration and didactic instruction is the norm. These impressions agree with Grimm et al. (1992), who say that:

> "In all schools we have equipment for experiments done by the teacher, and in most schools also for experiments done by the students."

They go on to say, however, that the equipment is old and that only five or six sets of equipment is available per class. This makes experimental work in large classes almost impossible. Henderson (1993), also mentions the old equipment and says that the teaching is generally "talk and chalk" with little in the way of teacher-student dialogue.

In contrast, a Manitoba science room is filled with the apparatus needed for lab activities. Most classroom have enough balances for students to work in twos or threes. The shelves around the classroom have all the various kinds of glassware visibly displayed. Chemicals and biological specimen are also often kept in the classroom. The junior high school science department in one of our schools where I taught for a year, was equipped well enough so that all students could get hands-on experience. The annual budget for just this junior high science department was over $700.00 per year, about two and a half times the German budget for their whole chemistry department.

It is significant to note that the Manitoba curriculum guide that is provided for the teacher is much more detailed than the German curriculum guide. The curriculum guide is divided into three parts for each topic or section:

1. Conceptual Structure
2. Objectives
3. Activities/References

This organization of materials provides a great deal of guidance for the Manitoba teacher. The activities sections include instructions for many actual simple activities that the students can carry out or that the teacher can demonstrate in order to make the concepts more meaningful. However, as mentioned earlier, the treatment is strictly qualitative instead of quantitative. Measurement of variables such as temperature, time, mass and volume are made but the interpretation is of a qualitative nature. No mathematical relationships are developed.

Interestingly, there is one quantitative activity suggested in the curriculum guide, which involves measuring temperatures at regular intervals and then graphing the result temperature drop "due to radiation". This activity uses 4 jars of equally hot water, with each jar treated differently:

1. uncovered
2. covered with paper
3. covered with foil
4. covered with paper and foil

The resulting data is then to be graphed to show differences in heat loss. The text authors attribute the heat loss only to radiation with no mention of possible conduction losses to surrounding air. All other topics or concepts are interpreted primarily in a qualitative manner.

The Manitoba science preamble emphasizes the problem solving approach to science. To this end the student is to learn to use the processes of science:

- observing
- classifying
- predicting
- controlling variables
- interpreting data
- designing experiments
- measuring
- inferring
- organizing and processing data
- hypothesizing
- defining operationally
- formulating models

Like the Manitoba preamble, the Bavarian rationale also emphasizes that the teacher is to connect the scientific discoveries to technology and to other disciplines like chemistry and biology. An appreciation for the contribution of science to the well-being of modern civilization is to be fostered. The student is to gain the ability to comment knowledgeably on the technical problems that arise in everyday life and to recognize the problems associated with technical progress.

Chapter 6. Comparison of Texts for the teaching of Heat and Temperature in Germany/Bavaria and Canada/Manitoba

The German text is titled "**Natur und Technik - Physik**" (1995) for use in Bavarian "Realschulen" at the grade 9 level. It was produced by a group of writer from various part of Bavaria and published by Cornelsen Druck, Berlin. I did the English translation.

There are three main topics presented in this text:

1) Heat and Temperature 2) Optics 3) Electricity

The Canadian text is titled "**Science Dimension 8**" (1992) for use in Manitoba schools at the grade 8 level. It was produced by a group of writers consisting mostly of practicing Manitoba science teachers and published by D.C. Heath Canada Ltd.

This text has five main sections which contain the complete work for the grade 8 level science instruction.

1) Plants and the Environment 2) Energy Resources
3) Cells and Organ Systems 4) Heat
5) Flight

The German text "**Natur und Technik - Physik**" is intended for grade 9 students in Bavaria. The section on heat and temperature is divided into topics that are almost an exact elaboration of the curriculum guide topics. The order is also practically the same in the text as in the curriculum guide. Naturally, the text has more detail than the curriculum guide and includes some details that belong to a topic but are not specifically mentioned in the guide. It seems clear that the text was written in response to the curriculum document.

The text begins with an introduction to the organization of the text. Each chapter contains seven different approaches to the topic.

1. Introduction

A colour photograph of a simple activity and a question or statement about it is used to catch the attention of the student. For example, a person is shown standing behind three bowls, presumably filled with water, labeled "warm", luke-warm" and "cold". The person stands with one hand in the warm water and the other hand in the cold water. The caption describes the scene and instructs that both hands be placed into the luke-warm water and then asks, "What do you notice?" (p. 4)

2. Experiments

Two types of experiments are suggested:

a) those that can be done using simple apparatus found at home and,

b) those that require specialized apparatus.

The simple experiments are marked with an upright "V" (Versuche = experiments) while the more complicated experiments are marked with a slanted "V" like the Greek letter "Nu". Every experiment is accompanied by clear colour photographs and/or diagrams. (Appendix p.3.)

3. Information

Important concepts are described and the specific vocabulary used by scientists is introduced to the student in a carefully organized manner. Specific methods used by physicists are presented. Scientific models and the mathematical representations used to describe scientific laws are included in this section. An example of this is the presentation of the particle model of matter and the effect of temperature on these particles.

4. Assignments

The assignments are designed to point out the many diverse connections that can be made with the student's own environment. The difficulty level of the assignments ranges from very easy to quite difficult. Some examples:

- Name several heat sources and indicate the energy transformations involved in each. (easy)
- Use the particle model to describe how a thermometer measures air temperature. (difficult)

5. Environment and Technology

Specific effects of technology on the environment are mentioned as well as safety precautions that should be observed when using potentially hazardous apparatus. The technology is also explained in quite simple terms using colour photographs of actual installations and "X-ray" diagrams so that the students can understand and appreciate the apparatus being used. A photograph of a nuclear power plant and its water cooling tower is placed beside a diagram which shows how water is circulated to remove unneeded heat in a manner so that the streams and lakes are spared the thermal pollution.

6. History

The historical development of the science discipline under study is emphasized. Names, nationalities and dates are presented for the development of models, theories and apparatus. Some of the early (pioneer) research is described. For example, Sir Humphrey Davy is mentioned as the inventor of the storm lamp and the miner's safety lamp in 1815. The situation in the coal mines that led to the necessity for such a lamp is described. Then the effect of the new lamp in terms of increased miner safety is explained. The connection between a social-economic problem and science and technology is thus made.

7. Summary

Questions that are based on the whole unit are found in this section. The main ideas/concepts/theories presented in the unit are then summarized to facilitate study and review.

As mentioned earlier, every page contains numerous full colour photographs or diagrams illustrating, not only the suggested experiments but also the concepts and theories.

The organization of the Manitoba text, like the Bavarian text, closely parallels the curriculum outline. The opening page in the chapter presents an incident to which the students can relate. People are coming out of a blizzard and into a cabin where a fire in the fireplace has already been started. The recorded conversation is in everyday terms that could have been used by the students themselves.

> "You know." said Darren, shivering, "this could be dangerous. We could be here all night."
>
> "Then we'd better keep warm. First thing is to stuff something in that gap around the door," suggested Stephanie. "Otherwise we'll lose all our heat." She tried to push her scarf into the gap.
>
> "Here, let me help you," said Jerri, gabbing the long metal poker from beside the fireplace. "Ow! Why is this thing so hot when I'm so cold?" (p. 236)

The first topic in this unit is presented in the form of a question, "What is heat?" A brief historical account includes Aristotle's ideas of the four elements and their relation to hot, dry, cold, and wet. The caloric theory is very briefly mentioned and explained and the reasons for discarding it are briefly mentioned. However, there is no mention of the scientists involved or the actual experiments that were performed in the search for an answer to the question "What is heat?" The authors simply state that:

> "Over the next sixty years, scientists carried out many heat experiments with solids, liquids, and gases. Their findings helped to develop the Kinetic Molecular Theory." (p. 239).

The main ideas of this theory are then listed. In an effort to connect the Kinetic Molecular Theory (KMT) to the students' experience the authors use the example of the mixing of chocolate milk powder with hot milk occurring faster than with cold milk. This is given as evidence that molecules of hot milk have more energy than molecules of cold milk and that heat must be a form of energy.

In a brief discussion the Caloric Theory is described as being the scientists' attempt to explain what actually happens when objects become hot. The development of accurate balances and the consequent discovery that there is no mass change upon heating and cooling is given as the reason why many scientists doubted the validity of the Caloric Theory.

In a separate page titled "Science Profiles", the authors profile Count Rumford's scientific contributions to our understanding of heat and temperature and very briefly mention his heat and friction experiments. Finally, Joseph Black (1728-1799), is mentioned as the first person to make a clear distinction between heat and temperature.

Each section in the chapter of the text ends with some questions that require the use or application of the presented material to real-life situations or to restate the presented concepts or theories. The chapter ends with a summary of the main ideas and a vocabulary list. Then integrative questions which require several ideas or concepts from the topic are given to the student. These are higher level questions which require fairly good understanding of the individual concepts and their relationship to each other. For example:

"When would alcohol be a better choice than mercury to use in a thermometer?"

"How could you use thermal expansion to loosen the lid on a glass jar?"

Experiments are referred to but are not outlined in the text itself. A separate lab manual, however, contains the details for the experiments. Reference to the experiments is made by name and number in the text. The result is that students do not have a convenient correlation between text presented materials and related lab activities. However, simple lab exercises that do not need special apparatus are suggested in the text in special "boxes" with the heading, "TRY THIS". The following is one example of this:

> "Prepare three basins or bowls of water: one very warm, one cold, and one about room temperature. Immerse your left hand in the very warm water and you right hand in the in the cold water. Leave your hands there for about one minute. Then immerse both hands in the third bowl. Are your hands reliable as thermometers? Explain why." (p. 255)

The text is supported by many photographs and diagrams but most are in black and white only. Environmental effects of heat are integrated into the discussion of topics. In all cases the discussion is in qualitative terms rather than in quantitative terms. In fact, the authors say,

> "In future science studies you will learn how to do heat calculations. For now it is enough to know that the amount of heat transferred from a hot body to a cold one depends on three things: the masses of the bodies, the kinds of materials they contain, and their temperatures." (p. 262)

Measurements of temperature and volume of water used and mass of hot objects are made but calculations of heat exchange, coefficients of heat etc. are not done.

The text does relate the heat concepts to devices used by students in their every-day life and to the explanation of environmental effects. Some examples are:

friction:	- useful for walking, driving, holding things
	- harmful because of heat generation, wearing of tires and scraped skin
heat transfer:	- a thermos jug, sun-earth relation, convection winds, pollution distribution, heating systems in buildings.

Finally, for an easier and more detailed comparison of the textual content, I have constructed the following table:

	GERMANY	MANITOBA
1. human sensory temperature interpretations	X	
2. fire as an element (Aristotle)		X
3. particle model of matter mentioned and assumed	X	X
4. changes of state in matter	X	X
5. kinetic molecular theory (KMT)		
- assumptions stated		X
- theory just mentioned	X	
- evidence for belief in KMT given	X	
6. caloric theory - pro and con evidence	X	X
7. distinction between heat and temperature	X	X
8. sources of heat energy	X	X
9. Brownian motion	X	
10. description of various thermometer types	X	X
11. history of thermometer development	X	
12. Fahrenheit, Celsius, Reamure, Kelvin scales	X	
13. heat energy and work --> temperature rise	X	(only heat energy)X
14. inner energy (internal)	X	(thermal energy)X
15. factors affecting internal energy	X	X
16. temperature = average particle energy	X	X
17. expansion effects of heat	X	X
18. friction effects	X	X
- Count Rumford's cannon boring experiments	X	X
20. specific heat capacity explained	X	

21. heat transfer methods	X	X
-convection-conduction-radiation	X	X
applications		
-heating systems	X	X
-land and sea breezes	X	X
- trade winds		X
-nuclear cooling towers	X	
- vacuum bottles		X
- cooking pots	X	X
- miners' safety lamps	X	
- home insulation	X	X
- arctic animal survival	X	
- human body heat loss	X	
- solar heating of the earth	X	X
- solar houses and green houses	X	
- solar collectors	X	
- greenhouse effect	X	
22. thermal equilibrium	X	X
23. latent heat (internal energy)	X	
24. thermal expansion and contraction	X	X
applications:		
-coefficients of thermal expansion	X	
- ceramic stove tops	X	
- pendulum clocks	X	
- railcar wheel manufacture	X	
- railway track distortions	X	X
- bridge section expansion joints	X	
- heat activated electric switches	X	
- expansion joints	X	X
25. anomalous heating behavior of water	X	

As suggested earlier, the Bavarian text includes more complicated concepts about heat and temperature than the Manitoba text. Considering the fact that the German students are about a year to a year and a half older than the Manitoba students, and that there is about twice the time allotment in Bavaria compared to Manitoba, this is quite understandable and justifiable.

Philosophy vs. Practice

As previously stated, the German pedagogical philosophy of science teaching advocates the participation of students doing hands-on experiments. However, Henderson (1992), says that in Germany the equipment is usually purchased for teacher demonstration purposes only and not for actual student use. It is stored in an adjacent room "out of reach of inquisitive students". In the German gymnasium, for example, where I spent a year (1982-'83) teaching physics and chemistry, I found one triple beam balance for the whole chemistry department. There was no equipment stored in the classroom itself. There were very few student lab activities for which I could find enough equipment so that the students could experience hands-on learning, even if only in groups of four or five. I taught physics at the grade 5 and 6 level and chemistry at the grade 8 level. Each physics class received one 45 minute period of instruction and each chemistry class received one and a half period of instruction per week. The equipment available to me was sufficient for demonstrations only.

Grim et al. (1992) report that normally schools in Germany have five or six sets of equipment for student experiments, (three or four students per group), but if there are more than 20 students in the class it is almost impossible to do experimental work with the whole group. Millar (1989), reports that students in Germany favored pupil experiments over demonstrations but the teachers' reasons for opposing experiments were based on the cost of equipment and the organizational problems of apparatus supply.

Personal Observations

The students in my classes in Germany were encouraged, but, because of the cost, not required to purchase the recommended text and workbook. Therefore I had to duplicate (copy) the pages from the workbook for those who chose not to or could not afford the books. The curious fact about the whole situation was that, had I not come to the school that year, those students would not have received this science instruction at all. Biology was a regular subject taught with the same time allotment and thus my being there doubled these students' science experiences that year.

The instructions that I got from the head of the science department was to keep the students occupied and interested and I was told not to worry about how much science I taught them. What I found was that the students were keenly interested when I tried to involve them and especially when I encouraged them to ask questions related to the science topics. They could make connections between the school science and everyday life. When I tried to have them do lab activities the way I was used to doing in my classes in Winnipeg they were always most eager to get involved. However, according to Henderson (1992), the "normal" communication in French and German schools is direct transmission and dialogue is unlikely to occur. This antiquated teaching style forces the students to learn by rote at home from the notes dictated and copied at school.

Concept Order in the Texts

A brief listing of the order of the concepts as they are presented in the two text suggests that the authors in each country have taken the age and mental development of the students into consideration when they planned the curriculum and when they wrote the texts. I assume that the topics are expected to be taught in the same order as they are presented in the text.

First, I will consider the order of the content in the Bavarian text. The first topic presented deals with temperature and thermometers giving the historical development of thermometers. Then the authors explain the Kinetic Molecular Theory (KMT) and some evidence for its acceptance. The usefulness of the KMT in explaining heat effects is discussed. There is, at this point, no mention of the caloric theory.

Temperatures and Thermometers

1. The unreliability of human temperature sense is demonstrated with the simple hot, warm, cold water bowl experiment.

2. Several different types of thermometers are described.

- liquid thermometers
- minimum-maximun thermometers
- bimetallic thermometers
- colour sensitive material thermometers
- fluid crystal thermometers

3. A discussion, with drawings, of ancient, (230 B.C.) and later thermometers outlining the history of thermometry follows. The determination of fixed points used by the various scientists is described and in this way the present practice is neatly linked to the past. By starting with a discussion of thermometer development the writers appear to share the thought of Sir Humphrey Davys circa1810, that

> "nothing tends so much to the advancement of science as the application of a new instrument".

The book is organized into sections dealing with specific topics relating to heat and temperature.

Section 1. Temperature-Internal Energy-Heat

A discussion of the KMT is used to show how scientists understand the structure of matter and the reaction of the particles to the addition of heat energy. The traditional diagrams of tiny circles are used to represent solids, liquids and gases. As evidence of the constant motion of particles the authors describe the investigation of pollen grains in a drop of water done by Robert Brown in 1827. The amazing, unending, random motion of these pollen particles is presented as evidence for the motion of water molecules. They mention that Brown originally believed that the pollen grains were actually some kind of life form. However, when particles of rust and dust behaved in the same manner, it became evident that Brown's conclusion could not be correct. Sixty years later the bombardment by water molecules as the cause of this motion became the accepted explanation. The German writers state that Brown's observations became the "sparkling" evidence for the theory of particle motion.

It should be mentioned that on the same pages various mini-experiments are outlined in text and/or photographs to suggest that there is a connection between motion, work and heat/temperature.

Section 2. What Happens During heating?

The question, "What happens during heating?" is presented as a historical problem that kept many scientists busy. The two competing ideas were:

a) heat is a fluid that is added to a substance during heating and removed during cooling, and

b) heat is the movement of invisible particles that compose all matter, are presented.

The cannon boring experiments of Count Rumford, the American who lived in Munich between 1775 and 1800, are briefly described. The fact that he could get as much heat from the dull drill bit rubbing away in the cannon cylinder as he liked, convinced him that this "fluid" really did not exist. He came to the conclusion that heat is really dependent on the motion that is brought to the particles of the metal during the boring action. The true nature of heat was not at all "fluid like (caloric)" but rather some kind of motion.

The authors then explain what our current understanding about the nature of heat is. They explain the concepts of average kinetic energy of the particles that relate to the temperature of the substance, of internal energy as the energy that the moving particles possess, of thermal equilibrium which occurs when two objects (substances) are in contact with each other and that heat energy moves from the hotter substance to the cooler substance until both achieve the same temperature.

2. The contributions of the German scientist, Robert Mayer, are described, including the scorn with which his ideas were treated by renowned scientists in 1842. These were his ideas:

a) The work done by agitating water raises the internal energy of the water particles.

b) To raise the temperature of a substance, energy must be added.

c) Law of "Conservation of Energy".

d) Energy can just be transferred from one object to another.

Only slowly did the attitudes of scientists to Robert Mayer's ideas change. However, in 1862 the Royal Institution of Britain declared that "no greater genius than Robert Mayer has appeared in our century."

Section 3. Using the Particle Model to Understand

The KMT is used to explain the following:

a) changes in volume in the three states of matter, solids, liquids and gases.

b) the different ways by which substances can be heated:

i) friction, ii) work input,

iii) contact with warmer bodies, iv) heat from a flame.

c) changes of state of matter, melting, evaporation, condensation, freezing.

Emphasis is put on the concept of internal energy being stored in the motion of the particles.

A special section that deals with the specific heat capacity of substances now follows. Emphasis is put on the study of water but other substances are mentioned in bar graph form in order to draw attention to the fact that water has by far the greatest specific heat capacity of any common substance.

Historical reference is made to the work-temperature change relationship investigations done by James Joule (1843). Quantitative problems are again presented for the student to solve.

Heat Transfer

The topic of heat transfer follows and deals with the movement of heat energy by convection, conduction and radiation. Colourful diagrams and /or photographs show practical applications that are likely to be part of the students' own experiences. (Appendix p.4.)

Section 1. Convection

Hot water heating systems which are widely used in Germany are clearly diagrammed to illustrate the phenomenon of convection. Potassium permanganate crystals are suggested to trace convection currents in lab containers to make convection visible. Reference is made to the use of natural convection currents by glider pilots. Land- and sea-breezes are explained using colorful diagrams.

Section 2. Conduction

Heat transport by means of **conduction** is then explained through the use of many diagrams. A table of values is used to show that each substance has its own conduction coefficient. Historically, the development of the miner's lamp is discussed as an example of the application of conduction technology by Sir Humphrey Davy. The different conduction coefficients for various building materials are shown in a table which emphasizes the practicality of this aspect of science in a country where energy costs are very high.

Section 3. Radiation

Radiation is introduced by showing a picture of people around a wood-fire with the observation that it feels warm except that a person's back remains cold. The concepts of radiation transmission and absorption are emphasized. Solar radiation is discussed in some detail in regard to its absorption and its reflection. Application is made to green houses and to solar houses as an effort to conserve conventional forms of energy by using radiant solar energy.

The last topic deals with the expansion of solids, liquids and gases during heating and the consequences in everyday situations:

i) railway and bridge expansion joints,

ii) heat sensitive electrical switches

ii) various industrial construction applications.

The abnormal expansion of water is outlined with the resulting consequences in nature, namely:

i) ice floats on water.

ii) fish can survive the winter in the water underneath the ice.

For all of the mentioned quantitative properties there are practice questions of various degrees of difficulty.

In the Manitoba text, chapters eight and nine deal with the topic of heat and energy.

Chapter Eight

Section 1. What is heat?

A photo of warmly-clothed children on snowshoes, has beneath it, the question, "In what ways do you think these children are keeping or producing heat to stay warm?". A brief discussion of Aristotle's four elements is immediately followed by reference to the caloric theory which was developed from the observations that heat seemed to flow from hotter to cooler objects. The invisible heat fluid was able to flow into a cooler substance and out of a hotter substance. The development of balances necessitated that this heat fluid be characterized as massless since no measurable mass change could be detected during temperature changes. However, because it could not explain heating by friction, it was discarded by 1860 and replaced by the KMT which could explain heat production by friction.

The other assumptions of the caloric theory are never described at all. The scepticism of some scientists as to the validity of the caloric theory is mentioned but no specific individuals are mentioned except in a special "science profile " page, Count Rumford is introduced as

"...an unusual thinker of his day."

Of course his cannon boring experiment is outlined, but only briefly, as the experiment that convinced him and many others that caloric heat fluid really did not exist.

Section 2. Sources of Heat

Reference is made to the previously taught Law of Conservation of Energy. Since heat is a form of energy, it cannot be neither created nor destroyed only converted from some other form of energy.

Mechanical energy

i) friction ii) compression iii) compression

Electrical Energy

i) conversion appliances designed for heat production

ii) waste heat from other appliances

Chemical Energy

i) burning of fuels ii) source of body heat from food molecules

Section 3. Heat and Changes in Volume

The KMT is used to explain all forms of thermal expansion and contraction. Thermal expansion in solids, liquids, and gases. Photographs of warped rails and cracked sidewalk slabs illustrate the damage that can be caused by solids expanding and contracting.

Section 4. Heat and Changes in Temperature

A brief discussion of liquid in glass thermometers introduces the concept of degrees to indicated changes in liquid volume as the temperature changes and the two reference points of O °C and 100 °C are explained. There is, however, no mention of the historical development of thermometers as in the German texts.

The merits and deficiencies of mercury and alcohol thermometers are outlined. Gas thermometers are mentioned as being preferable if minute temperature changes need to be detected. Metal thermometers of the bimetallic kind are explained and diagramed and their use in ovens stated.

The states of matter are diagramed using the familiar "ball" symbol for particles. The KMT is used to explain changes of state.

Differentiation between heat and temperature is introduced by reference to Joseph Black (1728-1799) as the originator of these two concepts. A cup of cocoa is used to explain the difference in a concrete way. The example used as "evidence" is a cup of cocoa at a temperature of 65 °C and a spoonful taken from the cup. Both have the same temperature but if spilled on one's lap a cupful will cause much more harm than the spoonful. The larger amount of liquid will have a larger heat content than the spoonful even both had the same temperature. Thus the fact that heat and temperature are not alike is demonstrated in a kind of "thought experiment" instead of actually carrying out a real investigation.

Then temperature and heat are defined in terms of "average kinetic energy" and "amount of thermal energy" being transferred.

The factors that affect heat transfer are discussed, with diagrams, in a qualitative way. Using two equal samples of cold water and adding:

i) 1000 g and 10 g of equally hot metal bars to the two samples.

ii) adding 1000 g metal bars at 100 °C and 200 °C respectively.

iii) Adding equal masses of equal temperature gold and silver bars.

Each section ends with a series of qualitative questions. Each section has a lab activity reference to the separate lab activity manual.

Chapter Nine

Section 1. Heat Transfer by Conduction and Convection

The heating of a metal poker with its end in a flame is explained in one sentence. "Beginning at the hot end of the poker, kinetic energy passes from one molecule to the next." This is the full explanation of conduction. Relative heat conductivity with silver as the standard = 1, is presented in table form. Insulators are defined as being non-conductors.

The effect of heating water in a beaker resulting in the molecules separating from each other and causing it to become less dense and thus to rise through the cooler , unheated parts of the water sample is explained and diagramed.

Natural convection currents in the form of land and sea breezes are explained and diagramed. Additionally, the trade wind are mentioned as being caused by the rising warmer equatorial air.

Temperature inversions and the resulting smog pollution are mentioned and related to the distribution of this polluted air to distant parts of the country by means of convection currents on a large scale.

Section 2. Heat Transfer by Radiation

Solar energy is the example use to introduce radiation as a means of heat transfer. Glowing hot objects such as candle flames and non-glowing objects such as hot clothes irons are said to radiate infrared waves.

The advantage of absorption by dark objects (clothes) and reflection by light coloured objects (clothes) are explained.

The vacuum bottle is used as an example of prevention of heat transfer.

Section 3. Heat Transfer in Buildings

Convection hot water heating systems and hot air heating are explained and diagramed.

Radiation-based heating systems in the form of electric baseboard heaters are actually misrepresented since it is primarily the convection currents set up above the baseboards that are responsible for the transfer of heat into the room. The text seems to indicate that radiation is the primary heat transfer method from electric base-boards and that convection is a secondary, minor heat transfer method. However, they correctly mention heating coils mounted in ceilings and heat lamps set in ceiling receptacles as transferring heat by radiation.

Reference to an air conditioner introduces heat pumps as a means of extracting heat from the outside environment and moving it inside the house.

Potential hazards of home heating systems and precautionary safety measures are outlined.

Section 4. Preventing Heat Transfer in Buildings

Insulation properties of various building materials are presented in quantitative values. The problems of improper ventilation and benefits of proper ventilation are outlined.

Each section ends with a set of qualitative questions.

Each section has one lab activity reference to a separate lab activity which is found in a separate lab manual.

Comparison of the Text Presentations

Connection to Technology.

Some of the applications of scientific concept to technology are definitely a reflection of local technology. This is true for both countries. Some examples include:

1. Germany has many nuclear power plants which employ the tall water cooling towers that can be seen in many places in the countryside. Manitoba, in contrast, has no nuclear power plants.

2. Glass ceramic stove tops are widely used in German homes and are thus familiar to German students. Although they are available in Manitoba, they are not as likely to be familiar to Manitoba students.

3. Each text has a table of thermal resistance values for building materials. However the materials listed are not the same. The German list includes slate roofs, hollowed bricks, steel reinforced concrete flooring as well as multi-pane windows. The units of conduction are used in the German text, $k = \frac{W}{m^2 \bullet K}$, i.e. watts per square metre per degree K of temperature difference. The assignments include calculations relating to the energy loss and the costs using current electricity rates.

The Manitoba list includes different kinds of building materials: fiber insulation, wood, styrofoam , and ordinary brick. No units are used. The numerical values are simply called "thermal resistance". The assignments include calculations regarding total thermal resistance for given wall constructions.

4. An interesting anomaly involves the inclusion, in the German text, of the polar bear and the arctic fox, which are typically found in the Canadian Northland and not at all in Germany. These animals are mentioned as examples of having natural adaptations for winter, namely growing a heavier winter coat and putting on a layer of fat. Also discussed is the surface area to body volume ratio which affects the minimum size of an animal that can survive the bitter cold of arctic areas.

Applications of Heat in Technology

The Manitoba text discusses the production of heat from:

a) the mechanical energy of running water to generators to electrical energy.

b) chemical energy in the form of burning fuels.

c) the body process of oxygen and sugar reacting.

The damaging effects of excess heat on railway tracks and sidewalks and streets to cause distortion and cracking are presented in word and picture form.

The use of bimetallic strips in thermostats to control furnaces is very briefly mentioned as a useful example of expansion and contraction. Expansion and contraction is again explained with reference to the KMT. The fact that liquids also undergo expansion and contraction is used as an opportunity to explain the operation of liquid thermometers. Then the pros and cons of several different types of modern thermometers are explained. Specifically, mercury and alcohol thermometers are compared and contrasted. The specialized uses of gas and metal (bimetallic) thermometers are presented. There is, however, no historical account of the development from "primitive" temperature measuring devices to our present-day modern devices. The Bavarian writers, on the other hand, begin with a detailed historical account of the development of the thermometer and then continue with the problem of explaining the difference between temperature and heat.

Heat Transfer

Both the Bavarian and the Manitoba text discuss and give examples of conduction, radiation, and convection. The Manitoba examples are, generally speaking, of simpler everyday devices such as:

1) metal pots and fire pokers, 2) non-metal pot handles
3) heated liquids in beakers or pots/kettles
4) Land/sea breezes 5) solar heat movement
6) vacuum (thermos) bottles 7) wood burning stoves
8) home heating systems using all three methods of heat transfer
9) home insulation

Any diagram/pictures are in black and white. (Appendix p.6-9)

The German text presents colour photographs/diagrams of:

1) home heating systems
2) nuclear reactor cooling towers
3) land/sea breezes
4) polar bear/arctic fox fur
5) a bonfire
6) passive solar heated house

In addition to these there are many simple student activities suggested along with colourful diagrams/photographs. (See appendix.)

Environmental Effects

In addition to the land/sea breezes, both texts present other environmental interactions. The Manitoba text includes two such interactions which involve heat:

1) temperature inversions and smog
2) turning municipal waste into energy

The German text presents somewhat more complicated concepts:

1) the transportation and release of the heat of evaporation in the atmospheric moisture moving from tropical to temperate regions.
2) absorption and reflection of solar radiation by the earth.
3) the greenhouse effect.
4) the anomalous behavior of water.

The higher age of the Bavarian students seems to have been taken into account when they planned the content of their text. Similarly, the Manitoba writers seem to have taken into consideration that students in grade 8 are not ready for the more complex concepts and have therefore presented the less complicated concepts only and in a qualitative way.

Relevance to Student Experience

The Bavarian text begins its heat unit with a picture of the discrepant event of a student holding one hand in hot water and one hand in cold water and then both hands together in warm water. The object of this exercise is to demonstrate the unreliability of human senses in determining hot or cold. This is a simple exercise which may well remind students of something that they have experienced but haven't really perceived to be a problem until they are formally faced with the need for an explanation. It is used to introduce the need for a more objective temperature measuring device, such as thermometers. The need for an operational definition of temperature is clearly demonstrated. The writers then go on to describe the various types of thermometers that have been developed. These thermometers give scientists an operational definition for temperature which all scientists can use in order to avoid creating any confusion when reporting the results of experiments. The use of this common discrepant event concerning the erroneous information of our sensory impressions, shows that these authors have used the students' experiences as a motivating device in their introduction to the study of heat and temperature.

The Manitoba text begins with a description of a blizzard in which the people enter a cottage where a fire is already burning in the fireplace. A discussion of this event could catch the attention of Manitoba students since many of them have experiences with cottages and with cold weather. Reference to cold weather and the need to keep warm is used as a spring-board to the development of the notions of heat by Aristotle and, later, when other scientists began careful heat experiments in the 1600's, temperature. The students' previous experiences are used to get the students interested in the topic of heat and temperature.

Many of the other concepts which are introduced in the presentation of the topic of heat and temperature, however, are concepts which the students have never heard of before. These concepts are completely new to the students and therefore they do not need to change any existing conceptions. These new scientific concepts are simply added to existing conceptions. Unfortunately, there is no competition between what they already know or what they think they know. Students are faced with integrating completely new concepts and theories with existing conceptions. Some examples of these are:

- the kinetic molecular theory	Germany	Manitoba
- kinetic energy of molecules	Germany	Manitoba
- average kinetic energy of molecules	Germany	Manitoba
- specific heat capacity	Germany	
- heat of fusion	Germany	
- heat of vaporization	Germany	

The higher age and maturity of the German students allows the inclusion of the more complex concepts which are omitted in the Manitoba curriculum. The age difference between the Bavarian students and the Manitoba students have been taken into consideration.

There seems to be, however, quite a difference between actual practice in the classroom and the official philosophy of science education in Germany. The inertial force of past practice of teacher demonstration/talking appears to prevent changes in actual intstructional practice. A much closer agreement between philosophy and practice seems to exist in Manitoba where more resources are available to supply up-to-date and sufficient apparatus for student involvement.

Evidence

The presentation of the kinetic molecular theory is quite different in the two texts. In the Manitoba text the assumptions of the theory are stated in point form. There is no attempt made to present evidence that would support the notion that the molecules are indeed in constant motion. The following is an example of an "evidential argument":

> "You have seen evidence that this (molecular motion) is so. For example, a chocolate drink powder mixes with hot milk faster than it does with cold milk. Evidence like this suggests that heat is a form of energy." (p. 240)

The authors then continue to use the notion of moving molecules to explain conduction of heat along the length of a fireplace poker.

The authors of the German text also state that the particles that compose matter are in constant motion and that, when heated, this motion increases. However, they present two dissimilar observable events which can easily be explained with the use of the notion that the particles are in constant motion. These dissimilar events are:

1) A beaker of water with a crystal of purple chemical (potassium permanganate) dropped in. The results, in the form of a picture taken 30 minutes later, show a completely purple colored liquid even in the absence of any agitation whatsoever.

2) A description of Robert Brown's investigation in 1827 with pollen grains in a drop of water observed with a microscope. The random motion of the visible pollen grains suggested to him that the pollen grains were alive but when finely powdered rust and dust particles also behaved in the same way he realized that this could not be the case. It was some sixty years later that the explanation was found in the notion that the constant molecular motion of water molecules was causing these tiny visible particles to move randomly.

The German text gives a physical phenomenon as evidence or "reason to believe" while the Manitoba text seems content to rely on the authority of the writers to convince the students that the kinetic molecular theory is valid and useful.

Heat and Temperature

An important aspect in the study of heat energy is the difference between heat and temperature. A sharp distinction was first made by Joseph Black (1728-1799), a Scottish chemist and professor of medicine at Edinburgh University who studied the state of thermal equilibrium that existed between objects in a room. It was Black who first conceived clearly that heat was a measurable physical quantity distinct from but related to the quantity indicated by a thermometer and called temperature.

The Manitoba text defines temperature as "a measure of how hot or cold something is" and then relates it to the average kinetic energy of molecules in an object. Heat is defined as a:

> "...the amount of thermal energy that flows from a hotter to a cooler body" p. 262.

Heat is then related to the molecular motion of the particles that make up an object. Later in the chapter the difference between heat and temperature is again addressed with the example of a cup of hot cocoa at 65 °C. The argument used is that a spoonful of the cocoa molecules will have less energy than the cupful because there are fewer molecules even though the molecules in the spoonful move just as fast as the molecules in the cup. The same argument is repeated by using a pot of soup and a spoonful of this soup. Both examples can be quite readily understood by students. In this way the extensive property of heat and the intensive property of temperature are explained even though these terms are not used.

The Manitoba writers then emphasize that temperature is not related to the mass of substance since the thermometer reading for the soup will be the same no matter how much soup there is. That temperature is not related to the type of material is explained but drawing attention to the fact that the soup contains many different kinds of molecules and yet has only one temperature.

The variables that affect heat transfer are then stressed, but also in the form of an argument without the use of experimentation:

1) Diagrams are used to illustrate that a large hot object has more heat than a small, equally hot object and will raise the temperature of a given amount of water more than the small object will.

2) If equal sized objects of different temperatures are dropped into equal given amounts of water, the writers' statement is that the hotter object will transfer more heat than the cooler object.

3) If equal sized objects of equal temperature but of different substance are dropped into given amounts of water, the amount of heat transferred will be different.

The Manitoba writers seem content to use the authoritarian argument approach to emphasize the distinction between heat and temperature.

The German text does not use any events with which students can be expected to identify when they begin to explain temperature. The Bavarian writers immediately associate temperature with the kinetic molecular theory and the average kinetic energy of the particles in a body. They state that:

> "It has been established that the average speed of the particles and the temperature are closely connected." (translation mine).

They refer to Brownian motion as evidence for the knowledge claim that, at a higher temperature, the particles have faster motion.

Several different methods of increasing the motion and thus the temperature of an object are suggested in the form of mini experiments. Heat is described as energy that is added to a body by various means:

a) work in the form of friction.

b) work in the form of repeated bending of a substance like a wire.

c) heat from a flame.

d) heat from a warmer substance in contact with a colder substance.

All of these effects are explained in terms of the increased motion of the particles in an object.

To emphasize that there is a difference between heat and temperature the Bavarian writers do use an example that would be familiar to the students. The perspective from which they approach the problem is quite different from the Manitoba approach but, perhaps both are equally effective. If equal amounts of energy were given to the water in a bathtub and to the water in a teacup, both would experience an equal increase in internal energy. However, in the bathtub of water the energy would be distributed to far more particles than in the teacup. Therefore the average kinetic energy of the molecules would hardly change at all and the temperature would stay almost unchanged. On the other hand, the fewer particles in the teacup receiving the same amount of energy, would experience a large increase in temperature. For this example, however, the writers do not explain how such an equal amount of heat could be added.

The Bavarian writers use diagrams illustrating 1000 Watt immersion heaters which delivers "precisely" 1000 Joule per second. If immersed in equal volumes of water at equal temperatures for 30 s and for 60 s, the latter sample would experience double the temperature increase compared to the former sample. Further, if one uses different masses, say double, of the same substance, the heater would need to be "on" for twice the time to produce the same temperature increase. This is a somewhat different approach used to explain the relationship between added heat and temperature change.

These various method suggest that there is no one "best" method to teach the difference between heat and temperature.

Chapter 7. Discussion and Conclusions

I have compared the curricular requirements and the textbook response to them for the teaching of heat and temperature in two quite different countries, namely Germany/Bavaria and Canada/Manitoba. These countries differ not only in language but also in their historical-social development and general outlook. The comparison involves the curricula and texts being used and the historical evolution of our understanding of and differentiation between heat and temperature. Also included are the results of research into science teaching by eminent researchers.

I began the discussion with the historical record of the development of the scientific concepts of heat and temperature. I have argued that knowledge of the historical development of concepts is very important in understanding how students learn science. Here I will briefly recapitulate the history of the development of these concepts and then determine whether or not there is evidence that curriculum developers and textbook writers use such a historical sequence or format for the presentation of the concepts of heat and temperature.

In the 18th century heat was considered to be a substance-like quantity that could be added to and removed from objects. It could be produced in quite simple ways, like by fire, by rubbing or from the sun. Every-day experiences shaped the concept and the language used to talk about it. Physical phenomena like expansion and contraction could be easily explained by the addition or removal of heat. Physical properties were attributed to this "substance" which eventually was named "caloric". By the beginning of the 19th century some scientist were considering another theory to explain the same physical phenomena. The theory of motion of particles was considered to be more fruitful. Competing schools of thought emerged, with the central question being, "Is heat a substance or is heat motion?" When scientists began to quantify their experiments the physical descriptions and properties of "caloric" became more complex and sometimes contradictory. For example, the expansion of water when cooled below 4 °C contradicted the notion that caloric occupies space. Moreover, the unlimited amount of heat produced by friction contradicted the notion that heat is conserved. Eventually more and more scientists became convinced that the caloric theory was not accurate and that the kinetic molecular theory, which was favoured by many in the scientific community, could explain all the heat phenomena observations without contradictions. Thus a major paradigm shift occurred in the scientific understanding of heat. The caloric theory was out and the kinetic molecular theory was in.

The understanding of temperature became possible only when an instrument was developed that could give an operational definition for temperature. This instrument was the thermometer.

The progression of these developments took many years and involved many people. When little knowledge was available, the concepts were simple and even contradictory, but satisfactory. When more information accumulated the concepts became more complex and were altered and sometimes discarded in favour of different, more useful concepts. The former, caloric concepts are, however, not forgotten and are still used in simple contexts, suitable for elementary school children.

Children have conceptions about the world that allow them to make adequate sense of their environment and live in relative safety. In the area of heat and temperature, children have a wide variety of experiences from which they develop their own conceptions. These conceptions are simple but quite strongly held (robust), with no distinction made between heat and temperature. The complexity of these preconceptions increases with age and maturity. The vocabulary used in connection with their conceptions is developed in the context of everyday conversation with family members, friends and the public media to which the student might have access. The social context in which many of these conceptions develop determines the vocabulary used and understood by the student. As the child gets older the conceptions become more complex as more information through experiences becomes available. Heat is seen as something that can move from one place to another and from one object to another. Heat becomes an entity, a substance, separated from objects. A further progression connects heat to degrees (numbers). Higher numbers signify hotter which is considered to represent more heat. Without formal instruction the differentiation between heat and temperature does not occur. Other important concepts that never seem to develop without formal instruction include: heat of fusion, heat of melting, specific heat

The teacher, who understands the same concepts as the students but from a science perspective, may use much the same vocabulary but with a different understanding of their meaning. Many scientific terms, which were developed when scientists investigated heat and temperature changes, are not used by students until they hear about them in a science class. Until this time they have managed quite well with their own conceptions which they can describe in their own words. Now they are faced with the necessity of formalizing these conceptions. To some students this is a welcome step toward sophistication and they appreciate it for the power it gives them in understanding what may have been baffling phenomena.

However, for many students who may not be particularly interested in academic studies in the early teen-age years, the personal motivation to learn new ways of thinking and explaining may not be very strong. These students may want to continue to use their own conceptions. Even carefully planned teaching strategies that develop the concepts of science and expand their use to many discrepant events may not be enough to convince these students that the scientific understandings are more useful.

Neither the curriculum guides nor the texts deal with the problem of students' retention of preconceptions. Both documents present the concepts in a certain order and depth but give no suggestions as to how the students can be motivated. It seems to be left entirely up to the teacher to make the "human" connection between the concepts and the students. The teacher must make the scientific concepts seem relevant and appear fruitful to the student.

Caloric Theory: a useful pedagogical device?

The once useful caloric theory of heat which allowed early scientists to understand heat in the context of their time, has been shown to be inadequate for explaining all heat and temperature phenomena. It was therefore totally discarded by scientists as an explanation for heat and temperature phenomena. Many science educators, however, suggest that in the initial presentation of this topic, it is still a useful theory as a pedagogical device. It can help students to get an early, partial understanding of heat concepts in a less formal way and help them formulate and develop their own conceptions or mental models especially for heat transfer. In fact, the theory can serve as a "bridge" between initial and full conceptual understanding of heat and temperature. We say, "Heat is added to an object." or "When an object cools it loses heat." Teachers and students can use this "discarded" theory even though it is not totally adequate for all heat phenomena. As long as there is no appreciable transformation of heat from or into any other form of energy it is useful and convenient to think of heat as a fluid that flows from one object into another. Many calorimetric determinations can be carried out equally well when thinking of heat as an indestructible fluid as by thinking of heat as energy. In my experience, the kinetic molecular theory can be taught and used simultaneously with the caloric theory without serious compromise of the integrity of science teaching.

This raises a new question. "Is there explicit or implicit evidence that the writers of the curriculum and/or texts make use of the caloric theory in their presentation of heat concepts?"

The introduction to the Bavarian curriculum document states that students will consider their everyday heat experiences and "realize that the particle model will be useful in the explanation of these experiences." (My translation.) The curriculum outline uses the term "Zufuhr von Wärme" which translates as "addition of heat". Interestingly, this reference suggests that heat is *something* that can be added to a body. However, it occurs in the outline only <u>after</u> temperature has been defined as the average kinetic energy of particles. Direct reference to the caloric theory is not ever made.

The Manitoba Curriculum guide starts with the statement, "Heat is a form of energy." The next statement is, "Temperature is a measure of the average kinetic energy." Particles of matter are not mentioned. Later statements also suggest a "substance like" nature of heat. For example:

"Heat can be transformed." and, "Heat can be produced." and, "Heat can be transferred." But nowhere is there any direct mention of the caloric theory.

The Bavarian text explains heat as being the result of particle motion and presents the evidence of Brownian motion, friction, diffusion in liquids etc. Then, in a special section, it deliberately presents the historical aspect of science and devotes almost a whole page to a description of the caloric "Wärmestoff" theory. It outlines briefly how the theory was useful as an explanation for some heat phenomena like expansion and contraction and then claims that the apparent massless nature of caloric was the major deficiency of the theory. Rumford's cannon boring work is described as the evidence that the caloric theory was not a valid theory. Not surprisingly, after this reference, the caloric theory is not mentioned again in the text.

The Manitoba text also presents the kinetic molecular theory and then refers to the caloric theory but without any details. The massless nature of heat along with the production of heat by friction is mentioned as major deficiencies of the caloric theory. The statement, "By 1860, the caloric theory had been discarded", is the last reference to the caloric theory. Rumford's work is mentioned very briefly as producing the final evidence for concluding that the caloric theory was not useful.

Neither the Bavarian nor the Manitoba documents use the caloric theory as a pedagogical device. Unfortunately, the theory seems to be presented only as a curious detail of history and nothing more. But as indicated before, the caloric theory can be used as a pedagogical device for the teaching of heat and temperature.

The Philosophy of Science Education in the Two Countries

Based on my interpretation of the curricular materials, the philosophies of science teaching in the two countries are not very different. Both stress the importance of active student involvement in guided science experiments/activities in addition to formal instruction. Students are to develop positive attitudes towards technology using science as the link to understanding and appreciating the benefits and hazards of technological advances for modern living. An awareness of environmental connections to science and technology is to be fostered so that intelligent decisions can be made regarding social and environmental issues.

In both countries there is an emphasis on scientific literacy. Students are to become familiar with the language used to describe natural and scientific phenomena. They are to acquire the ability to, not only understand the language of science and technology, but also use it effectively themselves.

Both countries emphasize the safety aspect of scientific activities. Knowledge of the hazards associated directly with science and technology is to be acquired and appreciated. However, the impact of science and technology on the environment is stressed in both the curriculum and texts.

The Bavarian curriculum is far more extensive than the Manitoba curriculum. As the Table on pages 54 & 55 shows, there are numerous topics in the Bavarian curriculum that are not included in the Manitoba curriculum. The concepts are also treated in a quantitative manner when possible while the Manitoba curriculum requires a primarily qualitative treatment. The expansion and contraction of solids, liquids and gases are presented simply as "When heated they expand and when cooled they contract. Unlike the Manitoba topics the Bavarian topics also include specific heats and coefficients of expansion and other concepts, as mentioned on page 41. The extra concepts and the greater depth of treatment in the Bavarian curriculum is probably due to both the higher age of the Bavarian students and to the larger time allowance for the study of heat and temperature in Bavaria.

The sequence of the concepts in the two curriculum documents is basically the same except that the Bavarian curriculum has many "extra" concepts added and many concepts are developed in greater depth. For example: the law of heat exchange, pressure effect on melting and boiling points, heat machines and others are more developed and listed on page 41.

The Bavarian text uses many more historical references to round out the presentation of the concepts. For example, Brownian motion, Robert Mayer's work regarding the conservation of energy, the development of thermometry and thermometers, Sir Humphrey Davy's invention of the coal miners safety lamp. It also has many suggested experiments which are included right in the texts while the Manitoba text has very little in the way of experimental suggestions. Both class and do-at-home experiments are included in the Bavarian text.

Chapter 8. Implications for Classroom

I have compared the science curricula about heat and temperature for Germany and Manitoba and examined a relevant text being used in each country. In this comparison I have outlined what is expected of middle school students in Manitoba and the somewhat older students in Germany. The research I examined that relates to the topic of heat and the comparison I made between the two curricula and the corresponding texts led me to some important implications for the classroom. These are:

1. Students develop their own "highly robust" conceptions in a social context which differs greatly from the context of the science classroom. Because of the "robustness" of these preconceptions, they may never be totally erased from the students' minds. However, research suggests that this is not a cause for worrying. Teachers should ensure that students be made aware of the diverse contextual differences that can exist when discussing heat. For example, when a cooking pot is placed on a stove we say "heat moves from the element into the pot." The scientific version would be, "the fast moving particles of the hot stove element cause the particles, of which the pot is composed, to vibrate faster. These cause the particles of the food in the pot to vibrate faster a in this way heat up the food." Students must be led to realize that each context uses a specific vocabulary to express basically the same idea. The students must be shown that it is quite acceptable to use alternative explanations as long as they match the context.
2. Research strongly suggests that even though the caloric theory is not considered to be an adequate explanation for heat phenomena and is therefore discarded by scientists, it was, nontheless, useful to help

scientists arrive at the currently used kinetic molecular theory. In the same way, I would argue that the caloric theory can and should be used by teachers today as an intermediate level of understanding of heat and temperature. The original historical process can be recreated in the classroom to facillitate the process of conceptual development in the minds of the students.

3. A clear difference in the expectations in terms of the number of concepts and the depth cf treatment in the two countries has been shown to exist. The German/Bavarian expectations are higher as befits the older students and the larger time allotment given to them. The concepts presented are more complex and they are given quantitative treatment. The older German students are likely more prepared for the formal thinking and understanding that is necessary for these concepts. These findings strongly suggest that it is very important for teachers to keep the maturity level of the students in mind when planning instructional materials and course content. Moreover, some flexibility must be exercised by the teacher when deciding on specific instruction for specific classes. I have argued that the Manitoba teachers need not be concerned by the qualitative emphasis and nature of their teaching of these concepts and have suggested that the quantitative treatment of science concepts for younger students can and should be delayed until the students are ready for it.

4. Teachers know that the proper progression in teaching is to move from what the student knows to what the student is required to learn. It is imperative, then, that the teacher, the textbook writer and the curriculum designer keep this in mind. In addition, the preconceptions held by the students must be considered by the teachers when new

concepts are being presented. When a teacher is cognizant of the preconceptions held by students, s/he can at least partially bridge the gap between them and the new concepts so that the student can more easily construct his/her own conceptions in a meaningful way. Wherever possible a student's personal experience should be used or taken into account in order to stimulate interest and facilitate comprehension and the construction of new meaningful conceptions.

5. The two texts use different activities and different examples to teach the same scientific concept. This suggests that a variety of teaching strategies can be equally effective. By using different approaches, the teacher can match or involve the students' own experiences in the process of conceptual development. The specific social and economic context of the student can and should be used. For example, the cooling towers of nuclear power plants, common in Germany, are used to illustrate the heat of vaporization in the Bavarian text. Blizzards, a common experience for Manitoba students, are used to introduce the unit on heat and temperature.

Further Research

A question that naturally arises is "Why is there so little research comparing science curricula in different countries?" Several reasons for this come to mind. First, the language difference requires that the researcher be fluent in both German and English and also be a science teacher having taught in both countries. These two conditions are seldom common to one person. I am fortunate in that I am fluent in both languages had the opportunity to teach science for a year in Germany. I was able to become acquainted with the German education system and to gain an interest in a comparison study.

Secondly, North American teachers who do get a chance to teach in German schools are usually assigned to teach English language courses, regardless of their normal school situation. Such teachers generally get a cultural experience only.

Thirdly, the physical distance between the countries makes the acquisition (availability) of relevant documents more problematic and thus discourages such research.

Finally, science education is international and science pedagogy and curriculum design are percieved as being fairly uniform. Although there are descriptions of curricula of secondary science courses for various countries in Europe in the literature, these descriptions may not suggest important implications for the science classroom

One important question, for which I do not have a comprehensive answer, is, "Do teachers in both countries actually allow the students to get a 'hands on" involvement?" Based on my experience in Germany and the observations that the classrooms are devoid of standard lab equipment and the observed scarcity of lab supplies in the storage areas, I am led to believe that the science teaching does not involve very much hands-on student participation. My own teaching style was affected by the lack of apparatus. Moreover, the German students' acceptance, without complaint, of the lecture-demonstration approach, suggests that this is what they are used to and what they expect from the teacher.

On the other hand, my experience in Manitoba schools is quite different. Frequent hands-on student group activities are used to foster interest in science and to develop the skills needed for problem solving. Manitoba students get restless and begin to complain when they are not allowed to participate as much as they think they should. There seems to be more of a mismatch between the philosophy and the teaching practice in Germany than we find in Canada.

A more complete and more up-to-date answer to this question can only be found by either direct observation in science classrooms in each country or by direct questioning of the science teachers. Since neither of these is an option for me at this time, the answer must be left for future investigation.

As mentioned earlier, very little research in science education of a comparative nature has been done. A continuation of this study could focus on the actual teacher practice in the classroom and laboratory. Various aspects of instruction and practice could be considered. The following questions suggest themselves: What kind of strategies are used to clarify the differences between the concepts of heat and temperature? Which laboratory activities are being used successfully? To what extent are equipment and supplies being provided for proper laboratory work? How large are the student groupings for lab activities? These are some ideas that might be explored to follow up this thesis.

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APPENDIX

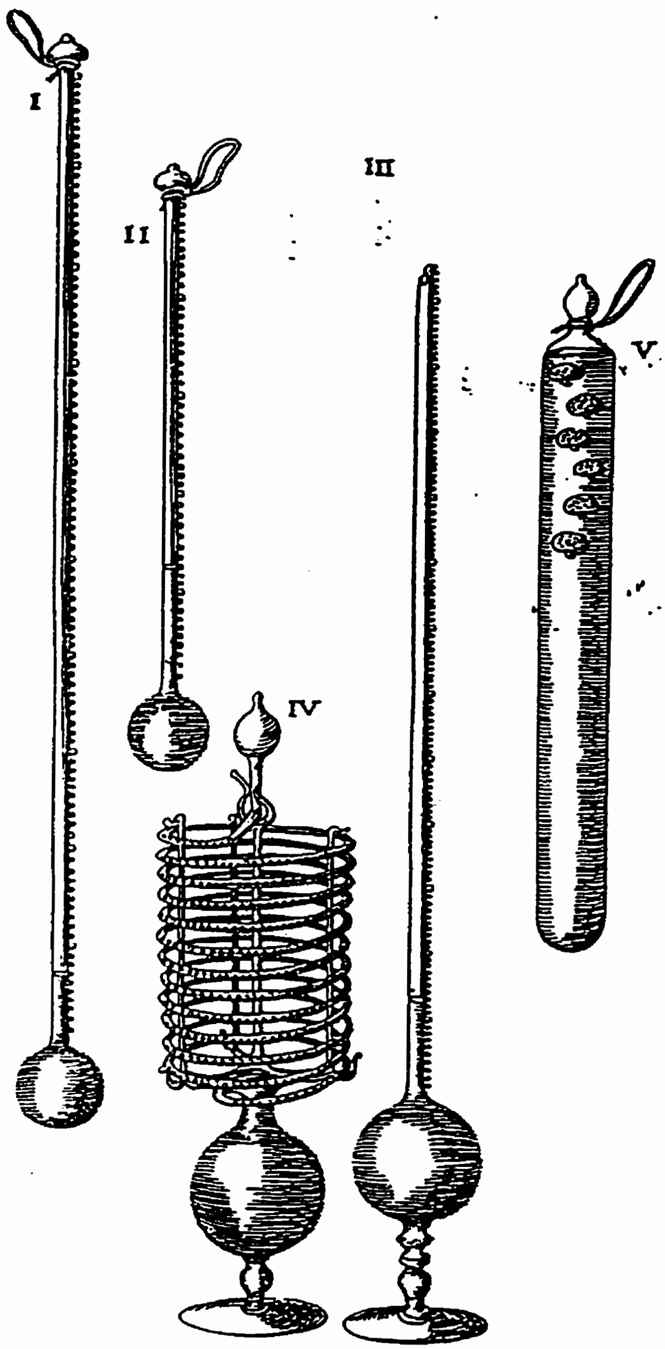

Plate I. Thermometers of the Accademia del Cimento.

1.

Von 1640 an widmete sich insbesondere die Akademie in Florenz der Entwicklung von Thermometern. Bild 4 zeigt ein dort gebautes Alkoholthermometer. Die kunstvolle Glaskrone stellt die Thermometerkugel (also das Vorratsgefäß für die Thermometerflüssigkeit) dar. Das schlanke Steigrohr ist fast einen Meter lang. 420 aufgeschmolzene Glasperlen bilden die Thermometerskala. Als Nullpunkt hatte man vermutlich den Flüssigkeitsstand bei größter Winterkälte gewählt und als Höchstwert den Stand bei größter Sommerhitze.

Natürlich war solch ein Thermometer ziemlich unhandlich. Man kam deshalb auf den Gedanken, das dünne Röhrchen in Form einer Wendel „aufzuwickeln" (Bild 5).

Wenn die Thermometer verschieden dicke Steigrohre oder unterschiedlich geteilte Skalen hatten, konnten die Messungen der einzelnen Thermometer nicht miteinander verglichen werden. Für die gleiche Temperatur erhielt man mit jedem Thermometer einen anderen Meßwert!

So war denn folgender Vorschlag, der auf den dänischen Astronomen *Olaf Römer* (1644–1710) zurückgeht, ausgesprochen vorteilhaft: Auf den Thermometerskalen sollten künftig die Höhen der Flüssigkeitssäulen bei schmelzendem Eis und bei siedendem Wasser markiert werden.

Der Schwede *Anders Celsius* (1701–1744) griff die Idee auf, die Schmelztemperatur von Eis und die Siedetemperatur von Wasser als *Temperaturfixpunkte* zu verwenden. Er schlug 1742 folgendes vor:

Der Abstand zwischen den Markierungen für diese Fixpunkte (d. h. der Fundamentalabstand) soll in 100 gleiche Teile eingeteilt werden; dabei ist Quecksilber als Thermometerflüssigkeit zu verwenden.

Allerdings betrug bei Celsius die Siedetemperatur des Wassers 0 Grad und die Schmelztemperatur von Eis 100 Grad! Erst später wurde die Skala umgedreht.

Nach dem französischen Naturwissenschaftler *René-Antoine Réaumur* (1683–1757) ist eine Thermometerskala benannt, bei welcher der Fundamentalabstand in 80 gleiche Teile unterteilt ist. Bis zum Ende des 19. Jahrhunderts wurden Temperaturen oft in °R (Grad Reaumur) angegeben. Die Reaumurskala wird heute nicht mehr verwendet.

In Amerika ist auch heute noch die *Fahrenheitskala* in Gebrauch. Diese wurde 1714 – also noch vor der Celsiusskala – von *Daniel Gabriel Fahrenheit* (1686–1736) aus Danzig entwickelt. Fahrenheit baute seine Thermometer in der heute noch üblichen Form und füllte einige mit Quecksilber, andere mit Alkohol. Offenbar angeregt durch einen Besuch bei Olaf Römer in den Jahren 1708 und 1709, suchte er nach Temperaturfixpunkten für seine Meßskala. Als einen Fixpunkt und als Nullpunkt seiner Thermometerskala wählte er die Temperatur einer Mischung aus Eis, festem Salmiak und Wasser („Kältemischung"); diese Temperatur soll auch die tiefste Nachttemperatur des bitterkalten Winters von 1709 gewesen sein. Fahrenheit hoffte, durch diese Wahl negative Temperaturen vermeiden zu können. Als zweiter Fixpunkt diente ihm vermutlich seine eigene Körpertemperatur.

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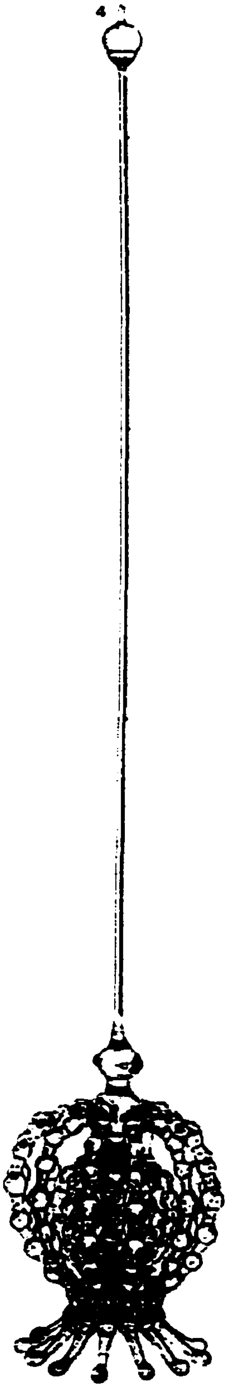

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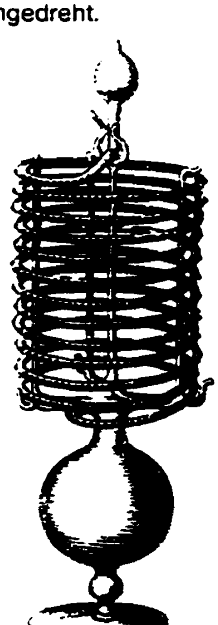


Fahrenheit markierte die Höhe der Flüssigkeitssäule bei diesen beiden Fixpunkten; dann teilte er den Abstand zwischen den Markierungen in 100 gleiche Teile. Die Schmelztemperatur des Eises betrug auf seiner Skala 32 °F (sprich: Grad Fahrenheit) und die Siedetemperatur des Wassers 212 °F.

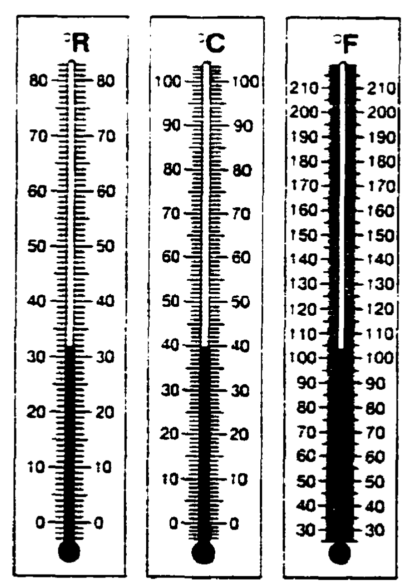
Die verschiedenen Temperaturskalen kannst du in Bild 6 miteinander vergleichen.

Fragen und Aufgaben zum Text

1 In der Oberpfalz wurde im Sommer 1983 eine Lufttemperatur von 40 °C (im Schatten) gemessen. Höhere Temperaturen wurden in Deutschland in diesem Jahrhundert nicht erreicht.

Gib diese Temperatur in °F und °R an. (Du kannst sie aus Bild 6 ablesen.)

2 In wieviel Teile ist der Fundamentalabstand bei der Reaumurskala und bei der Fahrenheitskala unterteilt?



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V 4 Bild 3 zeigt den Versuchsaufbau. Ziehe die Schnur wie eine Säge hin und her. Fasse anschließend die Schraubenzieherklinge an.

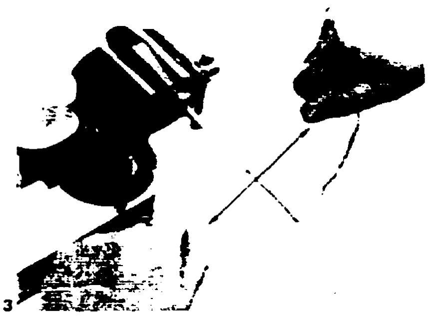
V 5 Für diesen Versuch eignet sich am besten ein elektronisches Thermometer. Klemme eine Wäscheklammer aus Holz an seinen Temperaturfühler. Ob sich die Temperatur ändert, wenn du die Wäscheklammer mehrmals drehst?

Notiere die Temperatur bei Versuchsbeginn und nach der 10., 20., 30., 40. und 50. Drehung.

Stelle deine Meßwerte in einem Diagramm dar (*waagerechte Achse:* Anzahl der Drehungen; *senkrechte Achse:* Temperatur). Was kannst du aus dem Diagramm ablesen?

V 6 Halte eine Fahrradpumpe mit einem Lappen fest, und bewege den Kolben etwa 20mal hin und her. Was spürst du, wenn du danach den unteren Teil der Pumpe berührst?

Wiederhole diesen Vorgang, halte jetzt aber die Pumpenöffnung mit dem Daumen zu.



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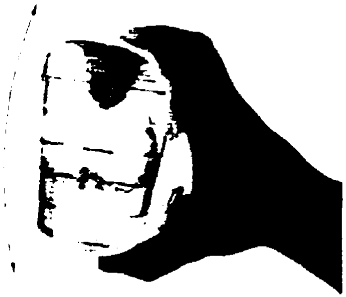

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V 7 Kann man Wasser dadurch erwärmen, daß man es eine Minute lang kräftig schüttelt?

a) Probiere es mit 100 g Wasser in einem verschließbaren Kunststoffgefäß aus (Bild 4). Miß die Anfangs- und die Endtemperatur möglichst auf 1/10 Grad genau.

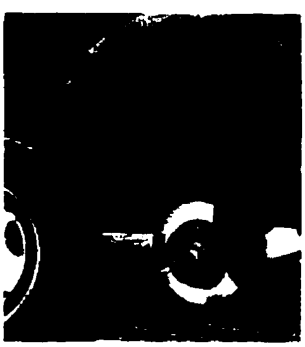
Wie ändert sich die Temperatur, wenn du zwei oder drei Minuten lang schüttelst?

b) Überlege, wie du in einem Kontrollversuch nachweisen könntest, daß keine Erwärmung durch die Hand stattfindet.

Nun können wir auch erklären, warum die Temperatur einer Bremsscheibe beim Bremsen ansteigt (Bilder 1 u. 2).

Die Bremsscheibe ist fest mit dem Rad verbunden und dreht sich mit ihm. Tritt der Fahrer auf das Bremspedal, so werden die Bremsbeläge gegen die Bremsscheiben gepreßt.

Die Oberflächen eines Bremsbelages oder einer Bremsscheibe (Bild 8) scheinen glatt und eben zu sein. Durch ein Mikroskop betrachtet, sehen sie aber wie eine Gebirgslandschaft aus (Bild 9). Beim Bremsen greifen die Unebenheiten der Oberflächen ineinander (Bild 10). Bremsscheibe und Bremsbeläge verhaken sich, werden wieder auseinandergerissen, verhaken sich von neuem usw. Dabei werden ständig Teilchen von ihren Plätzen gezerrt, federn zurück und schwingen dann heftiger als zuvor. Und das bedeutet ja nichts anderes, als daß die Temperatur der Bremsscheibe (und der Bremsbeläge) ansteigt.



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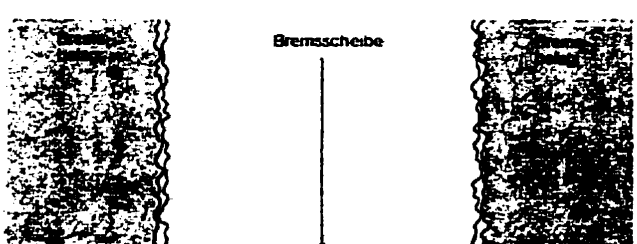

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Nimmt die mittlere Teilchengeschwindigkeit ab, so sinkt die Temperatur des Körpers.

Man kann sich nun vorstellen, daß die Teilchen irgendwann zur Ruhe kommen. Diese theoretische Vorstellung führt zu der Vermutung, daß es eine niedrigste Temperatur gibt. Tatsächlich hat die Temperatur einen solchen Tiefstwert: er liegt bei −273 °C.

Ein Ansteigen der Temperatur eines Körpers bedeutet immer, daß die mittlere Teilchengeschwindigkeit erhöht wird.

Ein Teilchen, das in Bewegung ist, besitzt **Bewegungsenergie** *(kinetische Energie)*. Erwärmt man den Körper, so nimmt mit der Geschwindigkeit der Teilchen auch ihre Bewegungsenergie zu.

Je höher die Temperatur eines Körpers ist, desto größer ist die (mittlere) Bewegungsenergie jedes seiner Teilchen.

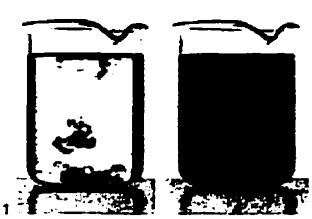
Fragen und Aufgaben zum Text

1 Die Temperatur eines Körpers steigt. Was bedeutet das für die Teilchen, aus denen der Körper besteht?

2 In V 7 wurde Wasser durch Schütteln erwärmt. Was geschah dabei mit den Wasserteilchen?

3 Erkläre V 4 im Teilchenmodell.

4 In das linke Glas von Bild 11 wurde gerade ein Körnchen Farbstoff geworfen, in das rechte schon vor 30 Minuten. Das Wasser im rechten Glas wurde nicht bewegt...



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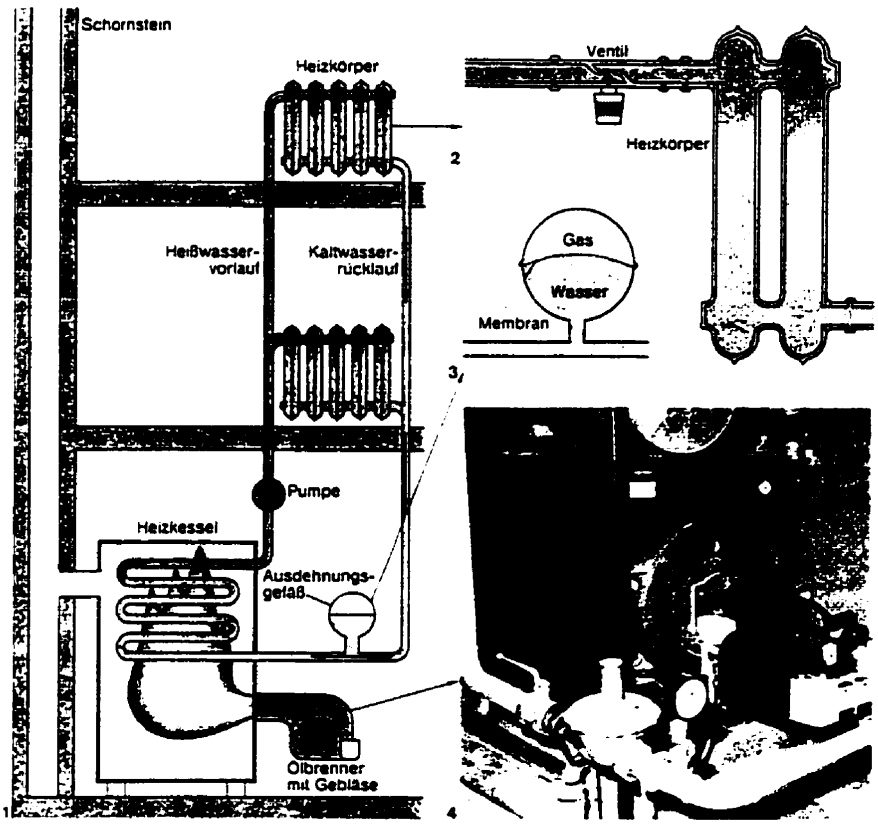
3.

Energie unterwegs

1 Die Konvektion

In Heizungsanlagen wird Energie vom Heizkessel in die einzelnen Wohnräume transportiert. Die Bilder 1–4 zeigen, wie eine Zentralheizungsanlage heutzutage aussieht.

- Wenn du die Möglichkeit hast, solltest du dir einmal eine Zentralheizungsanlage genauer ansehen. Versuche, die in der Schemazeichnung dargestellten Teile im Heizungskeller zu finden.
- Wie gelangt die Energie vom Kessel in die Heizkörper?
- Welche Aufgabe hat das Ausdehnungsgefäß?
- Häufig regelt man Heizungsanlagen mit Hilfe von Temperaturfühlern (Thermostaten). Es gibt Thermostate, die Einfluß auf die Vorlauftemperatur haben; andere wirken direkt auf die einzelnen Heizkörperventile. Überlege dir die unterschiedlichen Auswirkungen.
- Die Darstellung der Zentralheizung in Bild 1 ist vereinfacht. In Wirklichkeit läuft z. B. das kühlere Wasser des Rücklaufs nur zum Teil in den Kessel. Der andere Teil wird im Mischer mit heißem Wasser gemischt und als Vorlauf wieder in die Heizkörper gepumpt...



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V 1 Stelle einen Kochtopf mit Wasser auf den Herd, und schütte ein wenig Gries oder Reis hinein.

Beobachte, wie sich die einzelnen Körnchen bewegen.

V 2 In einen mit Wasser gefüllten Rundkolben werden einige Kristalle Kaliumpermanganat gegeben. Die Kristalle lösen sich langsam auf und färben das Wasser am Boden des Kolbens violett.

Nun wird ein Brenner seitlich an den Rundkolben gestellt (Bild 5).

Erkläre deine Beobachtungen.

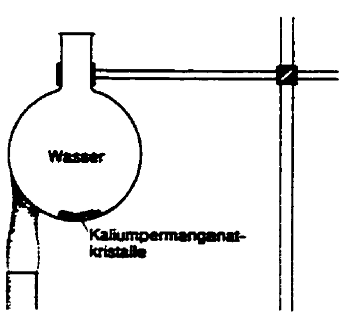
V 3 Halte ein einfaches Windrad (Bild 6) im Abstand von 20 cm über eine Kerzenflamme. Versuche, deine Beobachtung zu erklären.

Suche nach Stellen, wo sich das Windrad drehen könnte: z. B. über Herdplatten, Öfen, Lampen oder einem Bügeleisen. Probiere auch aus, in welchen Entfernungen sich das Rädchen noch neben den Wärmequellen dreht.

V 4 Eine brennende Kerze, die vor einer weißen Wand steht, wird mit einem Diaprojektor beleuchtet. Betrachte das Schattenbild der Kerze.

Ersetze die Kerze auch durch eine Glühlampe oder ein Bügeleisen.

Gib eine Erklärung für deine Beobachtungen.



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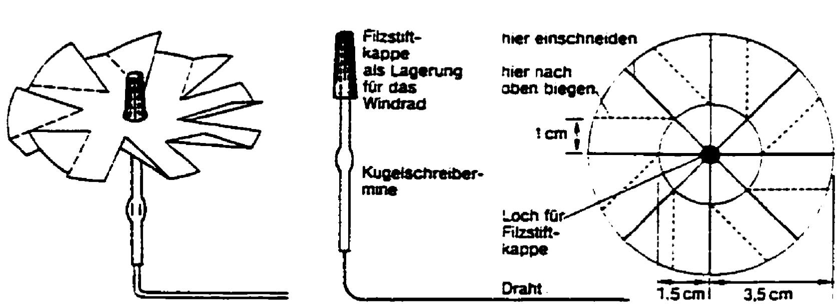

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4.

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Info: **Strömende Materie transportiert Energie**

In einer modernen Zentralheizungsanlage sorgt eine Pumpe dafür, daß das Wasser durch die Rohrleitungen und die Heizkörper strömt. Das heiße Wasser transportiert Energie vom Heizkessel in die einzelnen Räume. Das abgekühlte Wasser fließt dann zum Kessel zurück.

Ein solcher Kreislauf kann auch ganz von selbst in Gang kommen: In Bild 7 steigt das erwärmte Wasser nach oben und kühleres strömt von der Seite nach. Dieses Verhalten von Flüssigkeiten (und Gasen) läßt sich leicht erklären.

Wenn man einer Flüssigkeit an einer Stelle Energie in Form von Wärme zuführt, steigt dort ihre Temperatur. Der erwärmte Bereich der Flüssigkeit dehnt sich aus, d. h., sein Volumen vergrößert sich, und seine Dichte nimmt ab. Dieser Teil der Flüssigkeit ist somit leichter als die darüber befindlichen Flüssigkeitsschichten; er steigt nach oben. Dafür sinkt kühlere Flüssigkeit wegen ihrer größeren Dichte nach unten.

Man nennt den Energietransport, der an einen Transport von Materie gebunden ist, **Konvektion** (oder *Mitführung*).

Konvektion tritt nicht nur in Flüssigkeiten, sondern auch in Gasen auf.

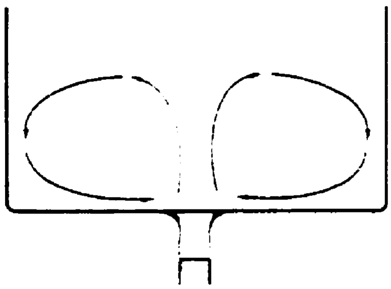
Die Energie wird von Materie mitgeführt. Mit dem Flüssigkeits- oder Gasstrom ist ein Energiestrom verbunden.

In unserer Umwelt gibt es viele Beispiele für die Konvektion. Sie tritt immer dann auf, wenn Flüssigkeiten oder Gase ungleichmäßig erwärmt werden, so daß Bereiche mit unterschiedlichen Temperaturen entstehen.

So erwärmt z. B. ein Heizkörper die ihn umgebende Luft. Diese steigt über dem Heizkörper auf, und kühlere strömt nach.

In der Natur gibt es ähnliche Luftströmungen: Die Sonne erhitzt die Luft über trockenem Untergrund (Getreidefelder, Felsen, Sand) stärker als über Wiesen, Wäldern und Gewässern. Die erhitzte Luft steigt auf. In der Umgebung sinkt kühlere Luft ab und strömt von unten nach.

Segelflieger nutzen die Aufwinde, um nach oben zu steigen. Sie fliegen enge Kurven in Bereichen aufsteigender Warmluft („Thermikblasen") und werden in die Höhe mitgenommen (Bild 8).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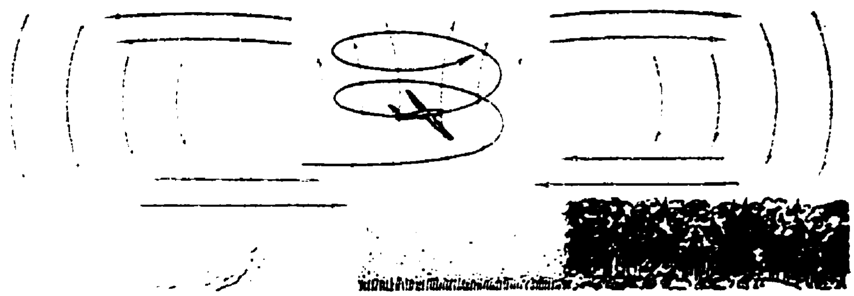
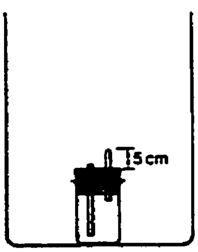

8

Aufgaben

1 Ein interessanter **Versuch**:
Ein kleines Gefäß wird mit gefärbtem, heißem Wasser gefüllt und mit einem Stopfen, in dem zwei kurze Glasrohre stecken, verschlossen (Bild 9). Was wird geschehen, wenn man es in ein Becken mit kaltem Wasser stellt?



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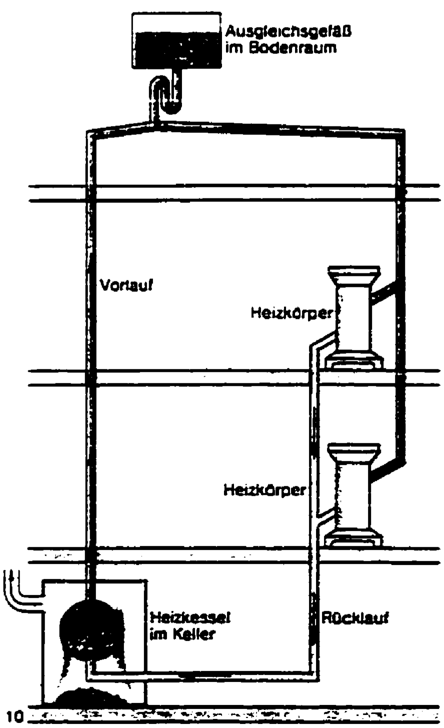
2 In Bild 10 ist eine Zentralheizung gezeichnet, wie es sie zu Beginn des 20. Jahrhunderts gab. Die verwendeten Rohre hatten einen größeren Durchmesser als heutige Heizungsrohre. Auch dauerte es länger, bis die Heizkörper warm wurden.

Welcher Unterschied besteht zwischen dieser Heizung und einer modernen Zentralheizung (Bild 1)?

Wie funktionierte sie?



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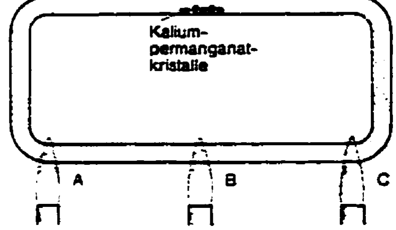
3 Wenn man die Tür eines geheizten Zimmers öffnet, kann man an einer brennenden Kerze erkennen, daß Luft oben aus dem warmen Raum heraus- und unten hineinströmt. Gib dafür eine Erklärung.

4 Bild 11 zeigt ein mit Wasser gefülltes, rechteckig gebogenes Rohr. Was geschieht, wenn das Rohr nur an der Stelle A, nur an der Stelle B oder nur an der Stelle C erhitzt wird?

Welcher technischen Anlage entspricht dieser Versuchsaufbau?



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5.

Figure 9-3 During the day, convection causes an onshore breeze.

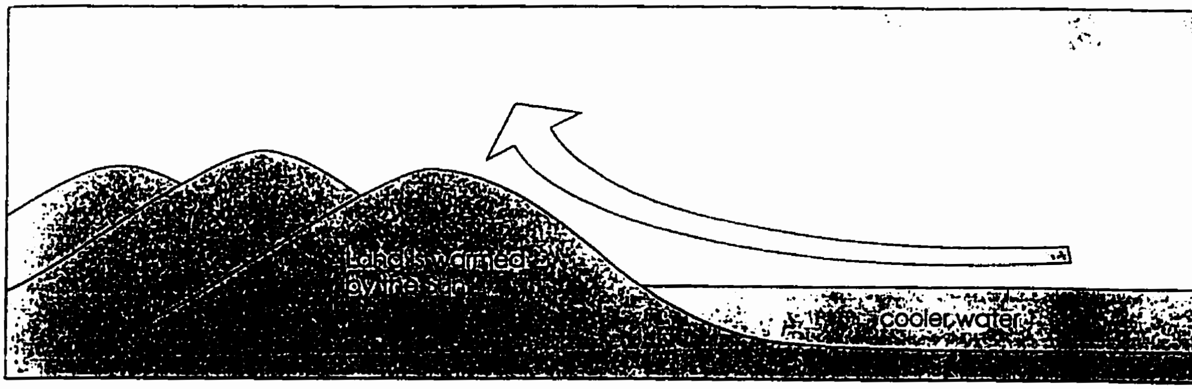
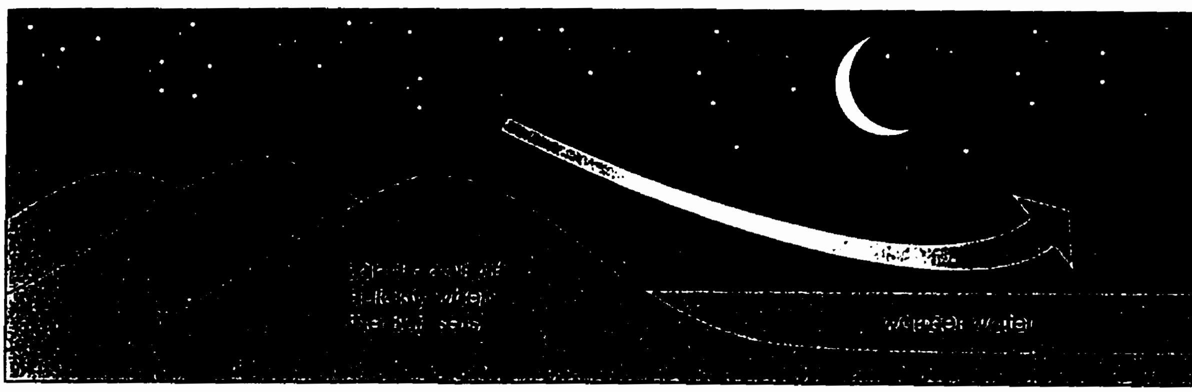


Figure 9-4 At night, convection causes an offshore breeze.



D I D Y O U K N O W ?

In a tea kettle, only the water nearest the element is heated by conduction. This hot water expands and rises by convection. Meanwhile, the surrounding cold water sinks down closer to the element. This sets up a convection current that gradually mixes the cold and hot water. Finally, all the water is heated to the same temperature (100°C), and boiling takes place.

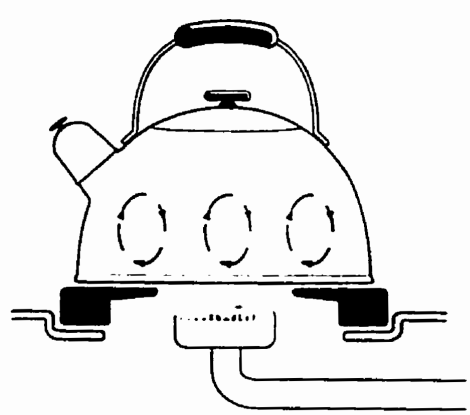
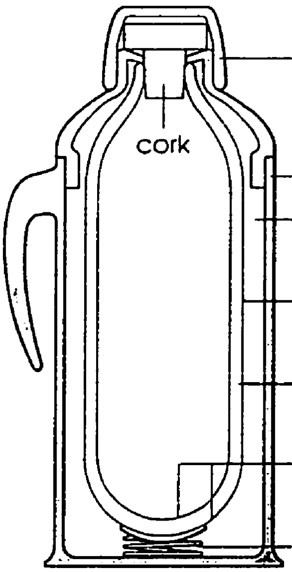
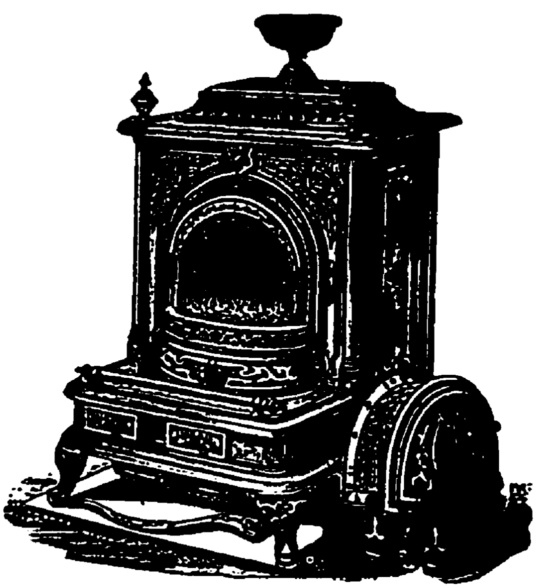


Figure 9-7 A vacuum bottle



Inquiry Questions

1. Suppose the bottle is filled with hot liquid and taken outdoors on a cold day. List the barriers that the heat energy will meet on its way. In what direction will heat energy travel?
2. Repeat Question 1 for a bottle filled with cold liquid and taken outdoors on a hot day.
3. Can a vacuum bottle prevent heat transfer completely? Explain your answer.



Franklin stove

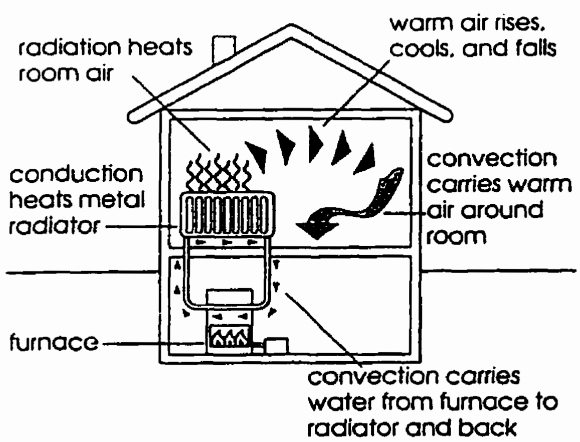
DID YOU KNOW?

Only about one billionth of the radiant energy the Sun gives off ever reaches Earth. All of that energy is eventually radiated back into space from Earth.

DID YOU KNOW?

The American publisher, politician, and scientist, Benjamin Franklin, invented the Franklin stove in the 1740s. It was essentially a wood stove fitted into a fireplace. The smoke went up the chimney, and the surfaces of the stove transferred heat throughout the room primarily by convection and radiation.

Figure 9-8 A hot water heating system depends mainly on convection to transfer heat, but conduction and radiation are also involved.



Hot Water Heating Systems

As you can see in Figure 9-8, the source of heat for this system is a fire in the furnace. This heat is transferred from the furnace to the rooms in the house mainly by the convection of water.

First, cold water is heated in pipes that pass through the furnace. The heated water expands and becomes less dense. This sets up a convection current. The warm water moves up the pipes to fill metal containers called radiators.

In the radiators, conduction transfers heat from the hot water to the metal. Radiation transfers heat from the hot metal to the air in the room. Heating the air sets up a second convection current that transfers heat through the room.

Meanwhile, the water in the radiator loses much of its heat energy. As the hot water cools down, its molecules crowd close together. Convection currents then carry the denser, cooler water back to the furnace.

Forced Air Heating Systems

In this system, heat is transferred from the furnace to the rooms of the home mainly by the movement of hot air. The first hot air heating systems relied solely on natural convection currents to move the air through a house. Heated air from the furnace rose naturally up through the hot air ducts to the rooms above. As the warm air gave up its heat to the rooms, it became cooler and more dense. Then it was pulled by gravity down the cold air return pipe and back to the furnace for reheating. The problem with the early system was that the air did not flow fast enough. Rooms farther away from the furnace were too cold.

Today, we use a forced air heating system that has a blower fan to improve the flow of air. (See Figure 9-9.) The result is increased efficiency and comfort throughout the house.

Figure 9-9 A forced air heating system uses a blower fan to assist natural convection currents.

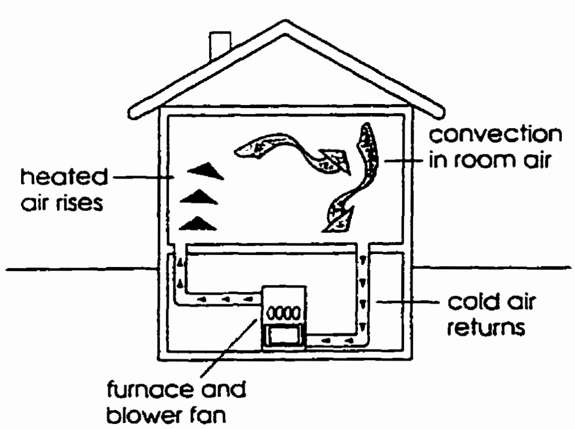


IMAGE EVALUATION TEST TARGET (QA-3)

150mm

6"

APPLIED IMAGE . Inc
1653 East Main Street
Rochester, NY 14609 USA
Phone: 716/482-0300
Fax: 716/288-5989