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TEACHING HEAT TRANSFER AND HEAT EXCHANGE

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By

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ABSTRACT

TEACHING HEAT TRANSFER AND HEAT EXCHANGE

By

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When helping secondary students learn (study) the phenomena of heat transfer and heat exchange there are a myriad of investigations students can experience to help them gain mastery of the material. The research summer of 2002 allowed the refinement of twenty laboratory investigations some of which were tested in the classroom in 2002-2003. The summer of 2003 facilitated the development of thirty-eight short activities and six additional laboratory investigations. The goal of this project was to use a constructivist approach to guide teaching and learning about concepts in heat transfer. This philosophy of learning builds on students' prior knowledge by involving them individually and collectively in a variety of activities and laboratory investigations that will change or verify their original perceptions. Will this constructivist approach help promote learning and enable instructors to know if new knowledge has been acquired? Teacher perception of a changed learning environment and the hard data from pre and posttest analysis speaks to the value of this method for teaching heat transfer and heat exchange.

DEDICATION

This thesis is dedicated to my wife, Marsha. Thank you for all your devotion and hard work.

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INTRODUCTION

This project addresses the use of constructivist principles to help students study the topics of heat exchange and heat transfer. Students were placed in a research environment where they sequentially investigated laboratory material directly related to heat transfer and heat exchange. This approach allowed a direct exposure to phenomena allowing observation and measurement of desired variables. Will their involvement in this activity and lab-oriented approach have a direct impact on their ability to learn the material?

Hudson Area Schools serve a rural, blue-collar community of approximately 2000 people. Of the 350 students that attend Hudson High School, 50-60% normally go on to college. The 18 members of the 2003-2004 Physics class, which served as the study group, all expect to attend college.

Students are exposed to the principles of Heat Transfer and Heat Exchange in Chemistry I, Physics and A.P. Chemistry. The abstract nature of these principles has caused both qualitative and quantitative problems for students. Over the past 10 to 15 years teacher developed laboratory investigations were used to enable students to qualitatively experience heat phenomena to make the quantitative process more apparent.

The interdisciplinary seminar, summer of 2002 allowed time to refine these investigations, arrange them in a logical sequence and try some of them out using the Chemistry class of 2002-2003. These students experienced seven labs (calorimetry and phase change) presented in a traditional objectivist, behaviorist format (teacher centered, teacher driven). During the research summer of 2003 this work was expanded to include a possible 38 short activities and six additional laboratory investigations.

The goal of this project involved presentation of material using constructivist principles instead of a teacher-centered objectivist/behaviorist format. The activities and labs would be approached in a manner that would access a student's prior knowledge. Laboratory investigations would be introduced and the students would then complete the laboratory activities and investigations, working together in cooperative small groups, to construct new knowledge. This new knowledge should help them make sense of what they experienced, allowing them to fit the new information to their prior knowledge base.

For students to fully appreciate the concepts of heat transfer and heat exchange teachers need to involve them in a meaningful process that will promote successful experiences. Roblyer, et. al., (1997) discuss B.F. Skinner's behavioral learning theory. "Skinner was concerned with observable indications learning had occurred and what those observations could imply for teaching. Skinner and others concentrated on observable cause and effect relationships". The teacher's job is to

> "...modify the behavior of students by setting up situations to reinforce students when they exhibit desired responses. Learning was viewed as a sequence of stimulus and response actions in the learner. Teachers can link together responses involving lower level skills and create a learning chain to teach higher-level skills. Teachers can determine the skills

needed to lead to desired behavior and make certain they are learned in a step-by-step manner."

Rosenshine, B (1986) emphasizes a behaviorist technique called Explicit Teaching. "Present material in small steps, pause to check for student understanding and elicit active participation from all students. This method sequences six important steps including daily review, presentation of new material, guided practice, corrections and feedback, independent practice and weekly and monthly reviews."

Nation at Risk (1983) pointed out that the educational community was not addressing how fast the world was changing and the fact schools needed to better prepare students for this new environment of change. Cognition and Technology Group, (1994) stated, "Schools must graduate students who are prepared to be lifelong learners. This involves a pedagogical shift from transmitting a body of expected knowledge that is largely memorized to one that is largely process oriented." Constructivist theory attempts to provide the avenue that can help achieve this end. Wilson, (1996) explains a constructivist setting as "a place where learners may work together and support each other as they use a variety of tools and informational resources in their guided pursuit of learning goals and problem solving activities".

Historically, Giambattista Vico (18th century) felt humans could only clearly understand what they mentally construct. This is the mental construction that occurs in the mind when learning occurs. Students will progress through their own natural curiosity as individual experience allows them to interpret their reality. Knowledge is connected to the idea that everyone constructs their perspective of the world by using their individual experiences. To make sense of experiences students create their own rules (models) and then may need to change them when new experiences fly in the face of accepted truth. von Glasersfeld, (1995, 1996) defined radical constructivism as a way teachers play the role of a "midwife in the birth of understanding" as opposed to being "mechanics of knowledge transfer".

To appreciate and implement a constructivist philosophy in a classroom, teachers need to change their attitudes with regard to the way students learn. Ernest (1995) asked, "What is knowledge, truth and reality and how do students arrive at knowing what they know? Knowledge, its nature and how we come to know are essential considerations for constructivists." Webster's dictionary (1992) defines epistemology as, "the study of the nature of knowledge, its origins, foundations, limits and validity".

Historically John Dewey, Jean Piaget, Lev S. Vygotsky and Jerome S. Bruner developed some of the initial ideas and thinking that could be applied to the classroom. John Dewey, Democracy and Education, (1916) equated education with action,

> "...knowledge and ideas emerged only from a situation in which learners had to draw them out of experiences that had meaning and importance to them. These situations needed a social classroom context, where students joined, worked with materials, forming a community of learners who built their knowledge together".

John Dewey, Experience and Education (1938) – also shared the belief that

> "...all genuine education comes about though experience does not mean that all experiences genuinely of equally educative. Experience and

> education cannot be directly equated with one another. For some experiences are mis-educative. Any experience that is mis-educative has the effect of arresting and or distorting the growth of further experience".

Jean Piaget's views addressed the psychological development of students. Teachers needed to understand the sequences in the developments of a child's mind. Fundamental to this process is the process of discovery. Piaget – in To Understand is to Invent, (1973) shares this insight, "To understand is to discover, or reconstruct by rediscovery, and such conditions must be compiled so in the future individuals are to be formed who are capable of production and creativity and not simple repetition." Children may accept misconceptions they later need to reconstruct as they rediscover relationships in classroom activities. Active involvement will build understanding through step-by-step discovery.

Lev S. Vygotsky, The Vygotsky Reader, (1994) believes,

> "...children learn scientific concepts out of a "tension" between their everyday notions and adult concepts. Presented with an adult concept from the adult world, the child will only memorize what the adult says about the idea. To make the concept his/her property the child must link that concept to the idea as first presented to him/her. This, however is not straight-forward because prior conceptions and introduced scientific concepts are interwoven and influence one another as the child works out his/her own ideas from the generalizations he/she already had and those introduced to him/her".

Jerome S. Bruner The Progress of Education, (1960) states that "A physicist has certain attitudes about the ultimate orderliness of nature...A young physicist needs some working version of these attitudes if he is to organize his learning in such a way as to make what he learns useful and meaningful in his thinking." He goes on to emphasize that mere presentation does not achieve this end and much research on learning needs to be done. Bruner concludes "but it would seem that an important ingredient is a sense of excitement about discovery – discovery of regularities (patterns) of previously unrecognized relationships and similarities between ideas with a resulting sense of self-confidence in one's abilities". The project described here strove to structure material used in teaching heat transfer in a way that the excitement of discovery could be personal for the student.

The activities and laboratory investigations needed a learning environment that would promote collaborative learning and enhance critical thinking. Wilson in Case Studies for Instructional Design, (1996). shared in "a constructivist-learning environment there is a place where learners may work together and support one another. There is need for a variety of tools and informational resources to allow pursuit of learning goals and related problem solving activities." In Gergen's (1995) view, "teachers are coordinators, facilitators, resource advisors, tutors or coaches". In this project, classroom philosophy was changed to see if students could be engaged in multiple activities in pursuit of multiple learning goals. The teacher needs to be coach, cheerleader, facilitator and go-fer. Johnson and Johnson (1996) point out that "Active exchange of ideas within small groups increased learning and promote critical thinking." Totten, et. al., (1991) concur.

> "There is also evidence that cooperative groups achieve at higher levels of thought and retain information longer than students who work quietly as individuals. The shared learning gives students an opportunity to engage in discussion, take responsibility for their own learning and become critical thinkers."

Slaven (1989) emphasized "in effective collaborative learning there must be group goals and individual accountability". Webb (1985) shared, "it is the group's task to ensure every member has learned something and it is in the interest of group members to spend time explaining concepts to group mates." Vygotsky (1978) corroborates this idea. "Students are able to perform at higher intellectual levels when asked to work in collaborative situations versus individual." Bruner (1985) articulates that, "cooperative learning improves problem-solving strategies because students are confronted with different interpretations of a given situation. A peer support system makes it possible for the learners to accept external knowledge and critical thinking skills and convert them to tools for intellectual functioning."

As students progressed from simple to more complex activities they need more guidance within the constructivist mandate. Classroom design must address this issue, McClintock (1971) felt "when students construct new knowledge they are "studying" and this term captures what is happening better that the term learning." Black and McClintock (1995) considered the design of "student support environments (SSE) versus instructional systems. Creating these student support environments allow teachers to create a place for study in a world of instruction. "SSE's should foster the construction of interpretation based on observations and background research information."

To help students deal with more complex ideas Collins, et. al., (1989) introduce the idea of

> "...cognitive apprenticeship, as a method of teaching processes that experts use to handle complex tasks. This is learning through guided experience based on cognitive skills (what students belief about a subject that affects their responses). Students observe the process by which an expert thinks and practices new skills which teaches them to learn on their own more carefully".

They go on to explain,

> "...this method involves modeling, coaching, and articulation where students need to share their knowledge and reasoning, reflection where students compare their problem solving with experts (% error, % difference) and exploration (push students into a mode of solving problems on their own). Students need to see the problem, form techniques and provide their own critical explanation".

Cognitive apprenticeship also addresses a constructivist concept called scaffolding. The learner needs to be guided from their prior knowledge state to what they need to know. Scaffolding uses teaching direction to help students experience activities that would normally be beyond their ability. Vygotsky (1978) emphasized that, "student problem solving skills fall into three categories; skills which the student cannot perform, skills the student may be able to perform and skills the student can perform with help". Teachers need to provide the necessary assistance (scaffolding) to allow students to work at their highest level.

To summarize, in a constructivist environment teachers create situations where they help students acquire skills and construct new knowledge. In this environment teachers need to encourage students, draw them out, be available, and converse with them as they probe for understanding. As students take ownership of their learning, direct experiences will generate questions that will determine a course of action as students fashion and develop their own thoughts. Their ideas may at first be confused and they need to feel free to share, whether right or wrong. Teachers need to remain flexible and objective while they pay attention to student responses and value student points of view. This is a new approach to learning where students seek knowledge versus receiving facts and ideas. Dialogue with students will open new pathways of inquiry and teachers will need to accept their new role as part of this process. This constructivist technique will require more from students and teachers. Its promise centers on student involvement in a process that will produce an expanded knowledge base as a result of student active participation.

IMPLEMENTATION

This project began with the distribution and collection of consent forms signed by the parents with the classroom work beginning January 5th, 2004. Students began this unit with a pretest consisting of fifty multiple choice and 30 short answer questions. (Appendix A) which was completed on the 6th of January, 2004. The project, completed in a 10-12 week time frame, addressed phenomena involved in heat transfer and heat exchange. Sequentially, students began with investigations of conduction, convection and radiation. They then investigated how to define heat in terms of calories and then evaluated simple heat exchange where various amounts of hot and cold water were mixed together. This simple calorimetry showed the need to consider the heat absorption of the calorimeter (Styrofoam cup), which was determined next. Students determined the mechanical equivalent of heat to establish rationale for equating calories and joules. This was followed by more involved calorimetry that determined the specific heat of a variety of metals and also the temperature of red-hot steel (iron). The next chapter addressed phase changes and the heats of fusion and vaporization. The project finished by investigating the heat of crystallization of liquid wax, the heat of combustion of wax, alcohol fuel and food (peanuts) and the thermal expansion of solids.

Throughout the project students demonstrated learning by writing lab reports, completing problems associated with the laboratory investigations, taking short quizzes to demonstrate problem solving skills, they also completed a survey to help evaluate the value of this unit from the student's perspective. During lab activities students were involved in a cooperative learning environment where they helped one another collect and process data. Students were also informally questioned during class to gauge their response to the activities and labs that were experienced. A weekly log was used to reflect on these perceptions. Additionally a photo/movie record of some of the daily work was used to chronicle student experiences.

Students were asked to write responses using a curriculum-wide approach used in all disciplines. Hudson High School adopted the John J. Collins "Developing Writing and Thinking Skills Across the Curriculum: A Practical Program for Schools to Develop Consistency in Writing Across the Curriculum". In (Appendix C), Type 1 and type 2 writing styles were explained. Type 1 encouraged students to get their ideas on paper. This is a means for students to generate ideas, recollect thoughts, gather data, explore new ideas or ask questions in their thinking and writing. The process is individual, quick, gives students time to think, and teachers insight into a student's knowledge. Type 1 writing can replace class discussion and can be used to access prior knowledge at the beginning of a unit.

Type 2 writing shows that the student knows something about the topic or has thought about the topic. It is best used as a quiz and would be the correct answer to a teacher's prompt. A prompt needs to be clear and have a definite answer. Students will make their own meaning by translating concepts into their own words. Type 2 responses are good for prompts that require limited, specific and predictable responses. Prompts would include the tasks; list, define or explain to generate simple, quick written work that generates a correct response. These can be good wake-up calls for students. The following is a summary of the activities and lab investigations implemented in each of the chapters of this unit.

CHAPTER 1

(Heat, Heat Transfer and Temperature)

Chapter One began with some historical background concerning heat, thermal energy and temperature (Appendix B). This material was then reinforced with four activities and three laboratory investigations to explore heat, heat transfer and temperature. Students were provided with activity sheets (Appendix C), divided into groups of three to five students and instructed to help one another to complete the activities in two days. Chart 1 provides a summary of the activities and labs.

Chart 1 Chapter 1 - Heat Transfer and Temperature		
Activity/Lab	Ideas	Location
Background on heat, thermal energy and temperature	Historical perspective	Appendix B
Activity 1 - Feeling temperature	Physical sensing temperature	Appendix C
Activity 2 - Estimation of temperature	Ability to match a situation with a temperature	Appendix C
Activity 3 - Historical Dialogue	Discussion of heat as a fluid	Appendix C
Activity 4 - Testing a thermometer	Measuring devices have an associated error	Appendix C
Lab 1 - Heat exchange	Physically sensing heat	Appendix D
Lab 2 - Heat loss	Measuring rate of heat loss from different materials	Appendix D
Lab 3 - Heat loss II	Measuring rate of cooling using a good conductor	Appendix D

Students first used prepared tubs of hot, warm and ice water to physically sense temperature. Following a sequence of steps students found their hands gave very different sensations when placed back in the same tub of warm water. In the second activity students were given fourteen temperature situations (on cards) and fourteen temperatures (also on cards). Following directions students were able to match up the situation cards with corresponding temperatures. This was a good cooperative learning exercise. Group members reminded or retaught one another to convert Celsius temperature to Fahrenheit. The majority placed situations in the correct order with no more than two to three errors. During the hour two members of the Physics class volunteered to read through a short play about Antoine Lavosier and his wife, Anne Marie, as they discussed his ideas about heat transfer. The two concepts addressed in this play concerned heat flowing as a fluid (caloric fluid) and the possibility that this caloric fluid had mass. A series of questions were provided to help students analyze the possibilities presented in the play. Students next used digital thermometers to measure the temperature of boiling water and ice water to show that there is error involved with any measuring tool (even if it is digital - ±.5°C). Their last activity in this section involved a variety of temperature conversions to refamiliarize students with formulas to interchange Celsius, Fahrenheit and Kelvin temperatures. Students then completed three-laboratory investigations, which included a hot brick in cool water, heat loss of different materials and heat loss from a good conductor to evaluate the effect of a difference between the temperature inside and temperature outside. These introduced the concept of heat exchange and the heat transfer processes of conduction, convection and radiation.

In Lab 1 students worked in larger groups of four to five students and qualitatively described how the hot brick interacted with the cool water. Next, they were invited to use smaller brick samples, a Styrofoam cup versus the larger coolers and make any measurements they could and do any calculating they desired. This was done to evaluate the extent of any prior knowledge that was attained in Chemistry the year before. When they finished measuring and calculating all were invited to share their methods with one another. This discussion occurred in my absence. Students were able to piece together enough prior knowledge to calculate the heat lost by the brick and heat gained by the water. However, the lab reports reflected that only one-third of the class could reason appropriately.

In Lab 1 Heat Exchange: A hot brick was placed in cool water. Students could physically sense the brick cooling and the water warming. Emphasis was placed on the fact that heat flows from hot to cold.

The next two heat loss experiments allowed students to see that different materials lose energy at different rates. Additionally, they also understood that the difference between the inside and outside temperature does make a difference in the rate at which heat is lost. Students were required to graph their data using Microsoft Excel.

The four activities and the three laboratory exercises provided a great start for the project. Students worked well in cooperative groups helping one another with activities and labs. These investigations laid the groundwork for future work involving heat, and transfer and the concept of temperature. Big ideas that were addressed included heat as thermal energy that moves from hot to cold. Heat is not a fluid and has no mass. There are different temperature scales and methods available to convert from one to another. Students also were able to observe that different materials transfer heat at different rates and that the difference in temperature has an effect on the rate of transfer.

CHAPTER 2

(Heat Transfer)

In Chapter 2 students examined heat transfer, explaining the processes of conduction, convection and radiation. The activities were for the most part qualitative with a small amount of graphing. Each activity was intended to address phenomena connected to one of these three processes. Chart 2 provides an overview of the first of these processes, conduction.

Chart 2		
Chapter 2 - Conduction		
Activity/Lab	Ideas	Location
Activity 6 - Transfer of E_k to heat energy	Conduction by friction as work converts to heat	Appendix C
Activity 7 - Process of conduction (analogy)	Use of a model to illustrate conduction	Appendix C
Activity 8 - Water is a poor conductor of heat	Activities show water conducts heat slowly (High specific heat)	Appendix C
Activity 9 - Atoms of substance	Determine the rate of conduction and relate to kinetic molecular theory	Appendix C
Activity 10 - Conduction of heat by metals	Metal gauze or screen conducts heat away from the flame	Appendix C
Activity 11 - Copper coil snuffer	Metal conducts enough heat away from flame lowering temperature below the kindling temperature of wax	Appendix C
Activity 12 - Reduce heat loss with insulation	Determine the rate of heat loss from cans insulated with different materials	Appendix C
Conduction problems	Quantitative work to connect activities to practical applications	Appendix B

To examine conduction by friction students used a hammer to pound a length of coat hanger wire, showing that work could increase kinetic energy, as reflected by a rise in temperature. Next, a glass tube packed full of small BBs connected to a vibrational device was used to demonstrate heat transfer. Students could see how the vibrational device (simulating a source of heat) set up vibrations in the BBs increasing their E_k. Because students would use water in future experiments they needed to be aware that water was not a good conductor of heat due to its high specific heat. Students did a variety of experiments with water and ice in a test tube to examine how water conducts heat. Additionally, they were surprised to find they could boil water in a paper cup and not burn the cup. Students then did a variety of trials to determine how fast heat was conducted through a wire or bar. Students were provided with different wires each with a thin coating of wax. They then heated the wire and timed the melting of the wax (students placed marks in the wax to help with the timing). Another technique involved placing wax dots on a metal bar and then placing tacks in the wax at regular intervals. Students then heated the bar and measured the time each tack fell. They also simply heated one end of a wire and held on to the other to see how long it took for the heat to transverse from one end to the other. The last two activities examined how conduction could be used to transfer heat away from a flame and lower the flame temperature. They could see how a fine mesh screen absorbed heat from the flame. No gas would burn above the screen because its temperature was effectively lowered below its kindling temperature (principle of the Davy Miner's lamp). They also used a copper coil snuffer to extinguish a candle flame. This device conducts heat away from the flame fast enough that the temperature drops below the ignition temperature of wax and the flame goes out. The students' prior knowledge focused on the need for oxygen to sustain the flame. They could see the flame still had access to oxygen but could not see how conducting heat away lowered the overall temperature.

Students enjoyed the conduction activities and did a good job writing lab reports. They were amazed at what could be learned from simple activities. Using wax to determine conduction rate provided visual evidence along with the BBs used as an analog for conduction. Boiling water in a paper cup caused conceptual problems. However, most students eventually realized that the water absorbed energy keeping the overall temperature below the kindling temperature of the cup. The copper coil snuffer also conducted heat away from the flame lowering the temperature below the kindling temperature of wax. However, the students wanted to hold on to the idea that lack of oxygen prevented burning.

Chart 2 presents all of the activities relating to convection illustrating how heat can change the density of a fluid, causing it to rise.

Chart 3		
Chapter 2 - Convection		
Activity/Lab	Ideas	Location
Activity 13 - Convection currents	Use black pepper or charcoal to trace presence of convection currents	Appendix C
Activity 14 - Convection in hot and cold water	Use food coloring to see how temperature affects convection	Appendix C
Activity 15 - Density and convection currents	Find mass of equal volumes of hot and cold water to prove hot water is less dense	Appendix C
Activity 16 - Convection currents from ink bottle	Cold water replaces the hot colored water forcing the less dense water to rise.	Appendix C
Activity 17 - Convection currents in test tube	Students can see less dense water rise and reverse situation to produce no convection	Appendix C
Activity 18 - Convection currents in air	Hot less dense air rises from by a variety of activities	Appendix D

The first activity allowed students to set up convection currents in water and oil that were traced with pepper or charcoal powder. Next, students put food coloring in hot and cold water and watched the rate of convection in both beakers.

The third activity asked students to measure the mass of equal volumes of hot and cold water. They were surprised when the hot water had less mass than the cold water. They then calculated the density of both showing that the hot water was slightly less dense than the cold water. The difference in density allows hot water to rise starting a convection current. In the next investigation a potassium permanganate crystal was placed in a test tube, which then was gently heated on the bottom to produce convection currents. A second tube was prepared and was heated at the top, which produced no convection. (The less dense water was produced on top therefore no current was produced.) Students then investigated convection in gases using a pinwheel, heat snake and watched a demonstration with candles and smoke.

Student lab reports on convection captured the concept addressed in the activity. By using a variety of tracers (pepper, charcoal, food coloring and $KmnO_4$) students could see the convection process develop as less dense hot water would rise and displace the more dense cold water or oil. The majority were initially surprised when they found hot water had less mass versus cold water for equal volumes. This activity illustrated why less dense hot water rises in more dense cold water.

Chart 3 sequences the activities that were used to involve students in their study of radiation.

Chart 4		
Chapter 2 - Radiation		
Activity/Lab	Ideas	Location
Activity 19 - Transfer of energy by radiation	Use of radiometer to show conversion of radiation to kinetic energy	Appendix C
Activity 20 - Feeling radiation	Feel radiation directly and then through thicknesses of glass	Appendix C
Activity 21 - Heat transfer by radiation	Radiation transfers energy quickly-conduction and convection cannot be involved with this quick transfer	Appendix C
Activity 22 - Different kinds of surfaces affect radiation	Determine how white and black can absorb and radiate energy	Appendix C
Activity 23 - Focus radiant energy	Show how the energy can be concentrated using a magnifying glass	Appendix C
Activity 24 - Reflect radiant heat waves	Students can redirect radiant energy with no loss of intensity	Appendix C
Activity 25 - Web research	Passive and active heated solar homes	Appendix C
Activity 26 - Check R-values on web	Practical cost of insulation to prevent heat loss	Appendix C
Activity 27 - Solar energy trap	Design a device that will absorb and trap solar energy and heat up the inside of device.	Appendix C
Radiation problems	Application of Stefan-Boltzmann equation to analyze radiation problems	Appendix B

To study heat transfer by radiation students observed a radiometer (light mill). Some students remembered light was an electromagnetic wave that had particle properties. The activity showed that light traveling at 3×10^8 m/sec was able to carry energy and can do work by making the radiometer spin. In the next two activities students interacted with radiation from the sun, an electric heater and a light bulb. They experienced the radiation directly and then placed layers of glass between them and the source. Students could feel how glass diminished the radiation effect of the source. Using the light bulb they could experience how immediate the heat effect was which eliminated by the processes of conduction and convection as the mechanism of heat transfer. The process of conduction is a point-by-point transfer of energy and takes time to occur. Convection moved heat up and away from the source. This was also reinforced when a glass plate was placed between the bulb and hand to block air movement, which would prevent conduction and convection. The fourth and fifth activities allowed students to use a magnifying glass to focus radiant energy and concentrate its intensity. The sun's rays were focused on white paper, black paper and the student's arm. They were able to cause the black paper to smolder and felt some discomfort when the light was focused on their arm. They repeated the investigation by using a mirror to redirect the sun's energy to a point above the mirror. When black paper was placed at that point they obtained the same results. This showed that the radiant energy could be redirected with no loss of energy.

After the activities were completed the students worked on problems where they calculated quantities associated with conduction and radiation. Using measurements of area, temperature and length, which could be related to the lab activities, students worked in groups to determine the quantitative aspects of these two processes. Thirty to forty problems were discussed to gain insight into how much energy is transferred during the processes of conduction and radiation and the rate at which the transfer occurs (Appendix B). For conduction the expression $Q/t = kA\Delta T/L$ k is the thermal conductivity, A the cross-sectional area in m^2. ΔT the difference in temperature and L the length in meters was used to process problem data. A review sheet was provided (Appendix B). Students worked on the problems that they could solve in groups and the rest were done together in class with teacher assistance.

Students used the Stefan-Boltzmann Law to evaluate problems associated with energy transfer by radiation. The expression $Q/t = \sigma Ae (T_0^4 - T_S^4)$ was used to process problems. (σ is a constant 5.67×10^{-8} $w/m^2 \cdot k^4$, A is the area in m^2, e is called the emissivity and is always between 0 and 1 and characteristic of the material T_0 and T_S are the temperatures of the object and surroundings in Kelvin).

Students also did a nice job on their radiation activities. Reports communicate a good understanding of the process and the speed at which they occurred. Activities using the magnifying glass and mirrors were two of the students' favorite activities producing results that were communicated in the lab reports. Their lab reports reflected research on refraction, focal point along with good diagrams of each process. When the mirror was placed in the system students were able to diagram how the focal point was changed, locate its new position. The activities helped develop a solid foundation for problems (Appendix B) using the Stefan-Boltsmann equation. Students worked well in groups to solve these exercises and were also able to solve similar problems on a quiz.

CHAPTER 3

(The Calorie and Simple Calorimetry)

In Chapter 3 students addressed two goals, 1) to define a unit for heat (the calorie) and develop a formula to determine its value; 2) to evaluate situations where heat is exchanged to enable students to see heat lost equals heat gained. Chart 5 provided a summary of the labs done that investigate these phenomena.

Chart 5		
Chapter 3 - Calorie and Simple Calorimetry		
Activity/Lab	Ideas	Location
Lab 4 - Introduction to heat measurement	Introduction of equation used to calculate heat	Appendix D
Lab 5 - The calorie (a working definition)	Using the equation to calculate heat gained	Appendix D
Lab 6 - How to check up on heat measurement	Students mix equal volumes of warm and cool water to determine heat exchanged	Appendix D
Lab 7 - Mixing hot water and cold water	Mix equal volumes of very hot and very cold water to determine heat exchanged	Appendix D
Lab 8 - Mixing hot water and cold water II	Mix unequal volumes of hot and cold water	Appendix D
Lab 9 - Mixing hot water and cold water	Mix unequal volumes of water at the same temperature	Appendix D
Lab 10 - Calorimeter constant	Determine energy needed to change the temperature of the calorimeter cup 1 degree C	Appendix D

Students first used varying amounts of water in Lab investigation 5 to determine heat gained. Next they mixed varying amounts of hot and cold water together in Styrofoam cups to show that the heat lost by the warmed water was equal to the heat gained by the cooler water (Labs 6 through 9) . They also mixed varying amounts of water at the same temperature to show that heat and temperature are not the same thing (Labs 4 and 9). In Lab 5 hot plates were placed on low settings and adjusted for 30 minutes so their heat production was constant. Using the same beaker, 5 trials were completed using progressively more water in that beaker in each trial. The beaker was then heated in the same spot on the hot plate for 2 minutes. Each amount of water should absorb close to the same amount of heat energy. Three to four of the five trials produced fairly good results. When the hot and cold water samples were mixed together students were required to predict the final temperature before the water was mixed (Lab 6-8). Student predictions agreed with the measured equilibrium temperature within at least 1.0°C. Students also noticed that the heat lost was not exactly equal to the heat gained and finally realized that the cup, although a good insulator, also gained and lost small amounts of heat. Lab 10 showed how much heat the calorimeter gained or lost for every °C. This value was called the calorimeter constant and an average class value was used in the calculations for the rest of the calorimetry experiments.

The students continued to do well in the laboratory. Teacher log reflects that the students needed less direction and were taking more responsibility for their own learning, as observed by the instructor. Their initial work on Lab 4 and 5 was a practical introduction to the calculation of the heat involved in heat transfer. Homework based on these labs was also much easier due to the lab experience. Using math skills associated with the lab experiments recently

gained they easily calculated the heat lost and gained in Labs 6, 7, 8 and 9 and were able to work at their own pace.

Chapter 4

(Mechanical Equivalent of Heat)

To establish qualitative and quantitative relationships between work and heat (Joules and calories), students were shown two demonstrations (Chart 6).

Chart 6		
Chapter 4 - Mechanical Equivalent of Heat		
Activity/Lab	Ideas	Location
Lab 11 - Mechanical equivalent of heat (Sargent Welsh Device)	Conversion of frictional work to heat	Appendix C
Lab 12 - Mechanical equivalent of heat (cardboard tube)	Conversion of gravitational potential energy to frictional heat	Appendix C

These two demonstrations showed how work (force x distance) was converted to frictional heat, causing a change in calorimeter temperature in the first case and a change in the temperature of lead BBs in the second case. Data collected performing these demonstrations verified the mechanical equivalent of heat was equal to 1 calorie = 4.18 Joules.

The two investigations needed to be completed as demonstrations due to cost factors. When using each apparatus one can feel the exertion of a force over a distance. In Lab 11 the 5kg mass (49N) was lifted off the floor using a nylon cord and hand crank. The nylon cord was wrapped around a copper calorimeter filled with water. As force was applied to lift the weight the nylon cord began to slip generating frictional heat raising the temperature of both the calorimeter and the water inside. By measuring the circumference of the calorimeter and counting the number of rotations students could calculate the height the weight would have been raised and therefore the work done in the process. The force applied was just equal to the weight lifted. Students needed to see how the work done (force x distance) was equivalent to the frictional heat produced.

In Lab 12 students measured out 1 kg of lead shot (lead BBs). These were placed in a 1.20 m long cardboard tube. The tube was then inverted 100 times to simulate lifting the lead sample to a height of 120 meters. When the shot hit the bottom the work done to lift the shot was converted to frictional heat. Students measured the temperature of the lead before and after the fall and used the known mass and specific heat to calculate the heat gained. The heat gained was equivalent to the work done to incrementally raise the shot 120 meters (in terms of Joules). These values again allowed the calculation of the mechanical equivalent of heat (1 calorie = 4.186 Joules).

These two demonstrations involved student volunteers to assist in the demonstration. Data generated in Lab 11 was collected and processed by the group. Students were able to determine the value of the equality (1 calorie = 4.18 J) with no assistance. Lab 12 involved more physical participation (inverting the rod 100 times). Two students did the physical work to lift the lead 120 meters. Data was not as conclusive as Lab 11 giving 1 calorie = 6.43 Joules. Students were invited to use the correct value and work backwards to analyze possible sources of error. This approach took time and patience on the part of group members as they argued possible problems and solutions. They finally agreed no mistake was made calculating work, measuring the mass of the lead or looking up lead's specific heat. The only possible source of error was ΔT, which should have been larger than was measured.

Chapter 5

(Specific Heat and Temperature Calorimetry)

In Labs 13 and 14 students used calorimetry to determine the specific heat of a variety of metals. In Lab 15 calorimetry was used to determine the temperature of a red-hot piece of steel. Chart 7 gives a brief introduction to each of these investigations.

Chart 7		
Chapter 5 - Specific Heat and Temperature Calorimetry		
Activity/Lab	Ideas	Location
Lab 13 - Specific heat of a metal	Determine the specific heat of known and unknown granular metals	Appendix D
Lab 14 - Specific heat of a metal II	Carefully measure specific heat of 5 known solid metals	Appendix D
Lab 15 - Temperature of a hot body	Determine temperature of a red hot price of metal	Appendix D

The assumption of Lab 13 using the first law of thermodynamics (conservation of energy) was that heat lost by granular metal (Al, Cu, Pb or Fe) equaled the heat gained by the water and calorimeter cup. Students equated heat lost with heat gained and solved the equation for the specific heat of the metal. The majority of the values were within 10% of the accepted value. Students were also challenged to use the known specific heat for the metal and solve for the equilibrium temperature before the mixing occurred. If the predicted T_{eq} was close to the experiment value they could be assured their experimental specific heat was also a good value. At least one student per group could do these calculations and was able to help the others solve for the predicted T_{eq}.

Lab 14 used the same basic technique but the samples were solid, not granular. Students heated the samples (Cu, Pb, Al, Tin and steel) in a beaker of boiling water with the assumption that the metal temperature was equal to the temperature of the boiling water. These hot samples were then quickly placed in prepared calorimeters and T_{eq} was determined. The procedure produced reasonably good values for the specific heats (most within 10%).

Lab 15 was done to determine the initial temperature of a red-hot piece of metal (temperature of a hot body) using an aluminum calorimeter containing 200g of 3-5°C water was prepared in advance. Students were to solve for the ΔT of the metal, which was added to T_{eq} to determine its initial temperature. Students then converted this temperature to °F because students still relate to Fahrenheit versus Celsius.

After the labs were complete students completed associated problems that mirrored the lab processes (Appendix B). They were able to treat the problems like a lab, which allowed them to process the information in a timely manner. Students were asked to make a data chart for each problem and then draw a temperature versus time graph that conceptually related how heat was gained or lost in that situation. The quantitative step could be placed on the graph to illustrate each heat loss and heat gain. Quizzes based on this homework also showed reasonably good command of this topic. All students scored above 58% with 11 students above 81%.

Chapter 6

(Phase Changes, Heat of Fusion, Heat of Vaporization)

Chart 8 introduces Labs 16, 17, 18, 19, and 20 that address what happens to heat and temperature during a phase change.

Chart 8		
Chapter 6 - Phase Changes, Heat of Fusion and Heat of Vaporization		
Activity/Lab	Ideas	Location
Experiment 16 - Phase changes (freezing and melting	To analyze temperature changes as water freezes and melts	Appendix D
Experiment 17 - Heat of fusion	Energy associated with melting of ice	Appendix D
Experiment 18 - Boiling point of liquid	Determine the boiling point of four unknown liquids	Appendix D
Experiment 19 - Heat of vaporization	Energy associated with the vaporization of water	Appendix D
Experiment 20 - Molar heat of vaporization of liquid nitrogen	Energy associated with vaporization of liquid nitrogen	Appendix D

Students made qualitative and quantitative observations of the freezing of water and the melting of ice. Temperature versus time data were collected and graphed for both processes resulting in a plateau on the graph at 0°C showing the freezing point of water.

The heat of fusion was investigated in Lab 17. Students determined the energy needed to melt 1.0 grams of ice at 0°C using a prepared calorimeter starting at 40°C. Students could easily calculate the energy lost from the hot water and relate that to the grams of ice that melted. Using heat lost = heat gained, the calories needed to melt 1.00 grams of ice was determined. This value is called the heat of fusion and equals 79.7 cal/g.

Lab 18 focused on students measuring the boiling point of water, saltwater, ethanol and methanol. The alcohols were heated in a water bath and not by a direct flame. When students graphed the results a plateau appeared on the graph when the liquid boiled away. The exercise showed boiling point was a characteristic property of a liquid and that the addition of a solute to water will elevate its boiling point (salt water).

In Labs 19 and 20 students measured the energy involved in a liquid-gas phase change using two different techniques. In Lab 19 students measured the heat of vaporization of water by condensing steam (at 99°C) to recover the stored potential energy that was used to originally evaporate the water. By determining of the amount of steam that condensed and the heat gained by the water and calorimeter students could calculate the energy liberated when one gram of steam condensed. This value was equal to the energy needed to evaporate that same gram of steam. Students did one or two trials depending on time available and were generally within 5% of the correct answer (540 cal/gram).

In Lab 20 students directly measured the heat of vaporization of liquid nitrogen. With Sheldon Knoespel's (Chemistry Department, M.S.U) help I was able to secure 10 L of liquid nitrogen that allowed the students to complete 3-5 trials. In the trial 60-80 grams of liquid nitrogen was added to 70°C water in a larger-nested colorimeter. The heat from the hot water was used to evaporate the liquid nitrogen. Students determined the heat of vaporization in terms of J/mole.

Again their answers agreed with the accepted value within 5-10%. This was the most popular lab as students felt like real scientists as the nitrogen induced fog spread over their lab sites.

Chapter 7

(Expansion, Heat of Crystallization and Combustion)

The final laboratory investigations (Chart 9) explored in this project began with the thermal expansion of solids. Students then completed laboratory exercises that addressed the heat of crystallization of wax, energy content of food, heat of combustion of wax and the energy content of fuels.

Chart 9		
Chapter 7 - Expansion, Heat of Crystallization and Combustion		
Activity/Lab	Ideas	Location
Laboratory 21 - Linear expansion of solids	Measure the coefficient of linear expansion	Appendix D
Laboratory 22 - Heat of crystallization of wax	Determine heat released when wax changed from liquid to solid	Appendix D
Laboratory 23 - Energy content of foods	Measure heat produced when 1.0 gram of food burned	Appendix D
Laboratory 24 - Heat of combustion of candle wax	Heat produced from burning 1.0 gram of candle wax	Appendix D
Laboratory 25 - Comparison of energy content of fuels	Heat released when 1.0 grams of fuel is burned	Appendix D

Students used three laboratory techniques to evaluate the expansion of solids. The first two used micrometer devices to measure a rod's change in length. Students used this change in length to calculate the coefficient of linear expansion using $\Delta L = \alpha \cdot L \cdot \Delta T$ (α = coefficient of linear expansion, L = length, ΔT is the change in temperature). Copper, aluminum and iron were used in two different devices yielding values within 5% of the known value for α (coefficient of linear expansion).

Students then used the Introductory Physical Science (IPS) technique to measure expansion. Steam was passed through hollow rods that were clamped to the left end of the base of a pegboard. The right end of the rod was pulled down tightly on a T-pin that was taped to a 360° dial. The pin was on a bed of sandpaper, which caused it to roll and not slip as it expanded when the rod was heated. Steam passed through the rod causing it to expand to the right. As the rod expanded the pin rolled on the sand paper and the attached dial amplified this small change in length allowing it to be measured. Students used a micrometer to determine pin diameter and calculated its circumference. The dial reading indicated the percent of one full rotation. This value multiplied by the circumference gave the change in the rod's length. This value was then used to calculate α, the coefficient of linear expansion. This provided surprisingly good values for α (coefficient of linear expansion).

The final four labs were developed as additional possibilities to challenge students' ability to design a process that addresses a particular problem. Students were asked questions and were provided the materials needed to complete necessary data measurements for each investigation. For example: When 1.0 gram of liquid wax changes into a solid, how much heat is released in the phase change? How much energy is released when 1 gram of food, wax or fuel is burned? The class was broken into four groups to see if any meaningful techniques could be designed. One member of each group shared information on the overhead. This resulted in a method that was used by each group to try to achieve a value that was acceptable. Labs were handed out after they tried their own technique with the end result that their brainstormed technique was the same as the lab report process. This was a great self-esteem booster.

Results and Evaluation

Evaluation of activities and laboratory investigations should measure and identify student improvement that resulted from their participation in the heat transfer and heat exchange unit. The data that was collected to help determine student improvement included written lab reports or short summaries, daily observation of student involvement, homework problem specific to the lab exercises and short quizzes specific to both homework and labs. Additionally, students were given a pre and post test (Appendix A) that included 50 multiple choice and 30 short answer/essay questions. A student survey (Appendix A) was also conducted providing their view of the project's value.

The majority of the students did average to above average (70% to 95%) work in the preparation of lab reports and activity summaries. The grading procedure was based on: the proper entering and labeling of data along with any relevant qualitative observations; complete and labeled calculation charts along with a discussion of error; a sample calculation showing all their work as proof of their ability to process the data and finally a summary/conclusion that either addressed the purpose or answered a series of specific questions. Student data, observations, calculation chart and sample calculations was 75% of their grade on this work with the last 25% based on summary/conclusion.

With respect to daily observations it was obvious by their actions they enjoyed the exercises and working in small groups to complete the activities/labs. Results of the student survey (Appendix A) were informative with respect to their perceptions of the effectiveness of the heat unit. The majority of the students agreed or strongly agreed with the following inquiry statements.

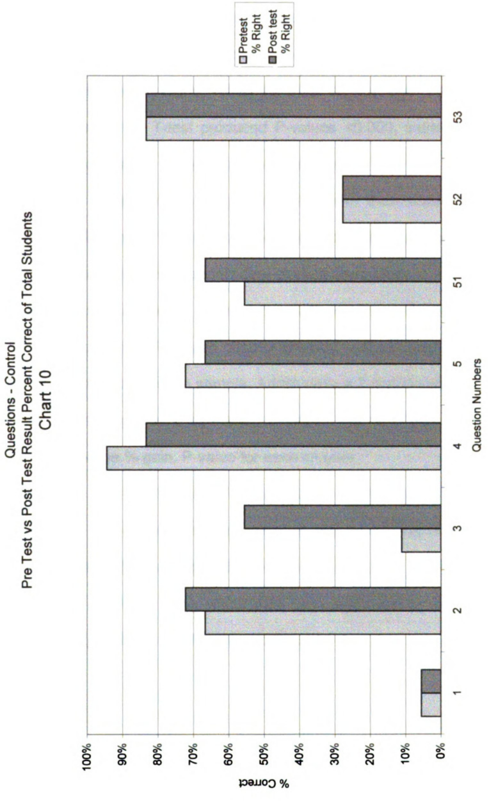
- 100% felt the activities and labs made the phenomena easier to understand.
- 100% also felt doing the labs helped them with associated problems solving in addition to being interesting and fun.
- 75% felt the labs were well organized while 92% said they were reasonably easy to follow. A complete summary of the survey is provided in Appendix A.

Students also commented (Appendix A) on what could be done to improve the unit. Some of the responses were duplicates and students agreed on eight constructive ideas for improvement. Students wanted more background information along with more prep time and diagrams on the lab sheets before the experiment was started. Most wanted additional time to complete additional trials (usually when data produced answers with a high percent error). One student wanted to use the lab report as a guide to write up his or her own version. Three students felt there was too much repetition (calorimetry). Most wanted to slow down and discuss the activities in more depth. This involved more notes on the experiments after they were completed. Students also felt there should be more evaluation over the material between labs (quizzes and short tests).

Students' comments also addressed what was happening in the classroom. Students commented that their classmates seemed to be having fun working in cooperative situations. They enjoyed the experiments, felt the lab sequence was good and the hands on approach helped them grasp the concepts. Their ability to interact and see what was happening made the work more enjoyable. Students also enjoyed the variety of labs and felt there was always something new. Many felt the summary/conclusion helped improve their writing while others were lazy in preparing the reports. One student tired of measuring the expansion of a rod and felt a new technique should be developed to illustrate linear expansion. Overall 50% of the class gave the unit an A while 50% graded it a B.

Homework specific to the labs is shown in Appendix B. These problems were completed in groups and any they could not resolve were discussed in class. Problems similar to the homework and lab calculations were given as short quizzes to evaluate student progress. (Appendix B)

The pretest and post test analysis contained eight questions that were included as a control group. These questions addressed topics that were not discussed in class or the laboratory. There were eighteen students (n=18) involved in the testing and a t-test was used to analyze data. Students scored 52.1% on the pretest control questions and 58.6% on the same questions in the post test. A bar graph shows the scores for these questions increased and decreased in a random fashion (see Chart 10).


Questions - Control
Pre Test vs Post Test Result Percent Correct of Total Students
Chart 10
% Correct
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1
2
3
4
5
51
52
53
Question Numbers
Pretest % Right
Post test % Right

Using T-test analysis the P-value for these questions was 0.722, which indicates no significant difference between the scores on these tests. This also suggests that the learning experiences in this project had no effect on their ability to answer these questions. When the other seventy-two pre/post test questions were analyzed the T-test produced P-values <0.000, indicating that there is a significant difference between the two test scores.

The questions on the pre/post test were then sorted so they could be aligned with one of the seven chapters addressed in this project. Bar graphs also were prepared to illustrate individual student improvement in each chapter while a second set of graphs focused on class improvement with respect to each individual question. For each chapter pre/post test percentages were calculated for each chapter question sample. Additionally a T-test P-value was calculated to indicate any significant difference between the two tests. Chart 11 gives a summary of the % gain, P-value for each chapter.

The individual question sets will reveal information on topics that may not have been addressed in enough detail as well as material that was covered well and was reflected in large student gain. There was a large improvement in question 3 (11% to 56%), which may have been due to the discussion of the speed of light when radiation was introduced.

Chart 11 - Test Statistics

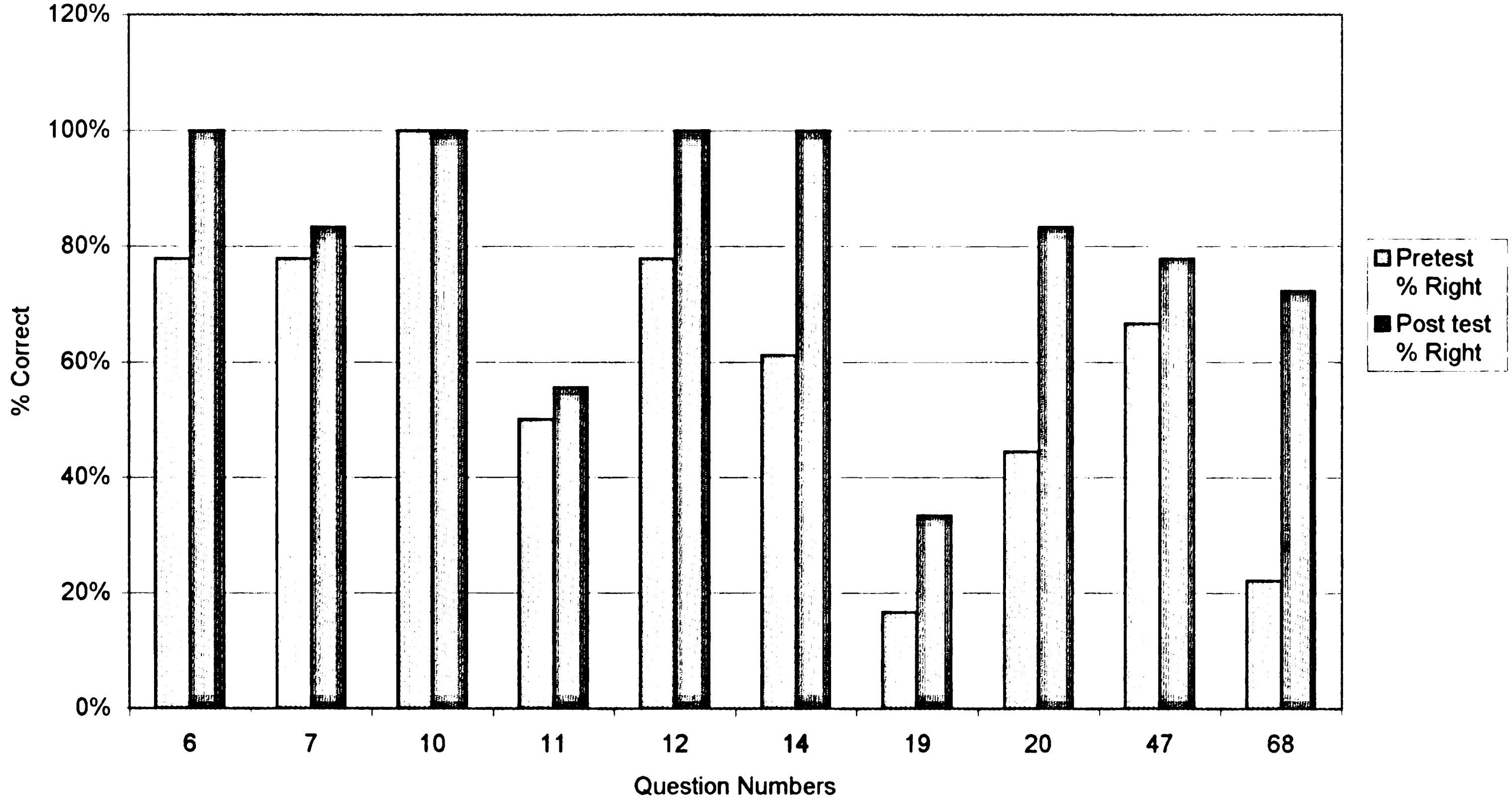
Chapter	Pre	Post	% Gain	P-Value	N
Control	52.1%	57.6%	5.5%	0.722	80
1	59.4%	80.6%	21.2%	<0.000	80
2	36.3%	59.8%	23.5%	<0.000	80
3	48.4%	75.4%	27.0%	<0.000	80
4	41.0%	72.9%	31.9%	<0.000	80
5	35.2%	75.0%	39.8%	<0.000	80
6	38.9%	58.7%	19.8%	<0.000	80
7	42.4%	64.4%	22.0%	<0.000	80
Total Test	42.2%	66.9%	24.7%	<0.000	80

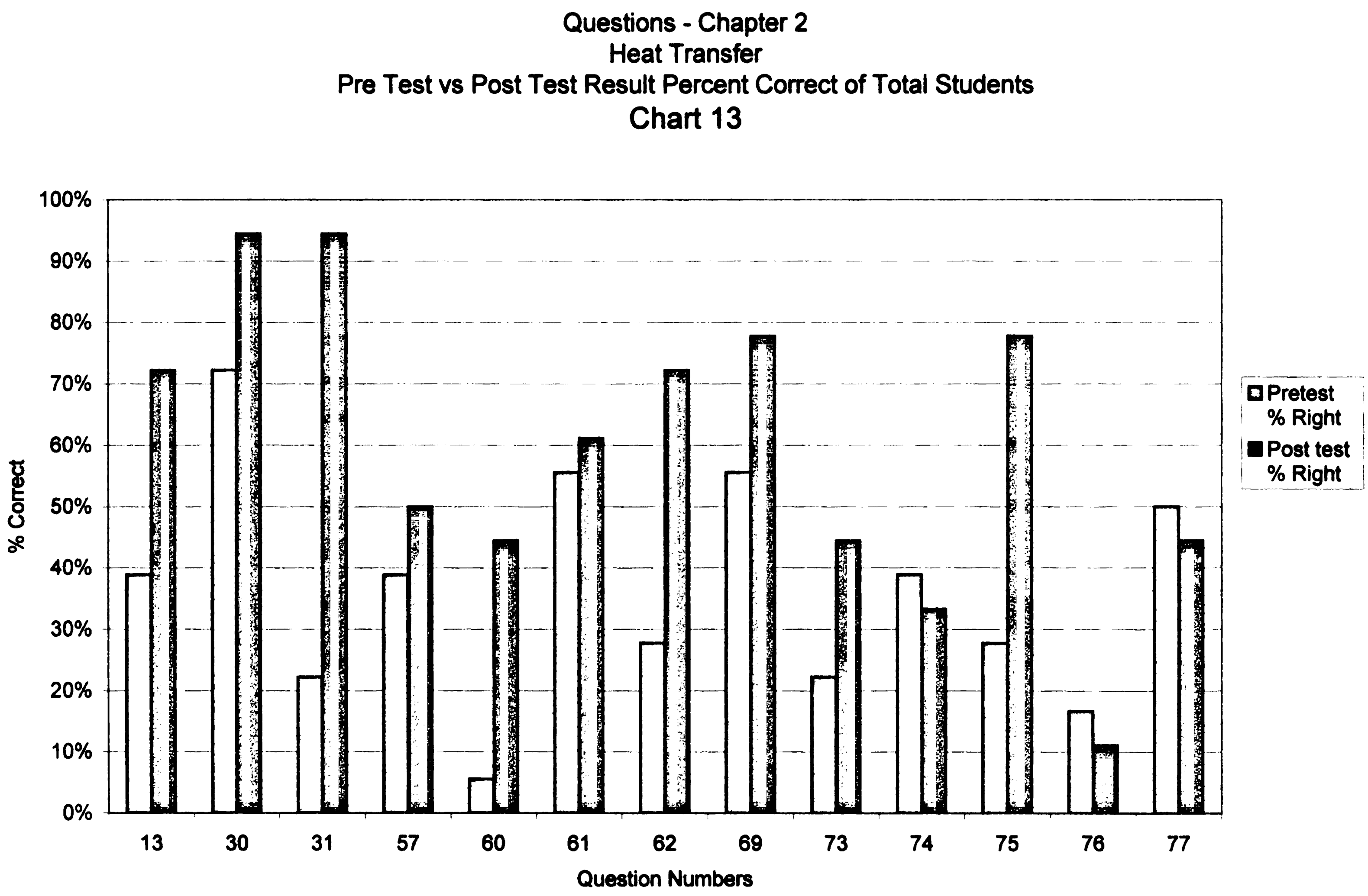
In Chapter 1 (Chart 12) the questions addressed temperature, kinetic energy, internal energy, temperature scales, energy flow, temperature conversion, and comparison of Fahrenheit and Celsius, absolute zero and reference points on temperature scales. Question 10 showed that students could name temperature scales before and after instruction. Questions 12, 14, 20 and 68 showed students could relate temperature to kinetic energy and could convert temperature and relate units between the freezing and melting reference points on a Celsius and Fahrenheit thermometer. Question 11 addressed energy flows from hot to cold while Question 19 addressed the fact that after –40°C the Celsius temperature is larger than the Fahrenheit value (17% to 33%). Overall there was a 21.2% gain in their ability to relate to this introductory material.

In Chapter 2 (Chart 13) students investigated the processes of conduction, convection and radiation. Students showed improvement in recognizing ideas related to conduction, convection and radiation.

Questions 57 and 60 were addressed in the laboratory and should have shown greater student improvement. Question 74 referred to an insulation lab that was not completed while question 76 also referred to an exercise that was not addressed (students may have confused reflection of light with the process of radiation). Question 77 was covered in Lab investigation 3. Students could see the greater the temperature difference the faster heat was lost. They graphed data to show this point and obviously the observation did not carry over.

Questions - Chapter 1
Temperature
Pre Test vs Post Test Result Percent Correct of Total Students
Chart 12




Questions - Chapter 2
Heat Transfer
Pre Test vs Post Test Result Percent Correct of Total Students
Chart 13
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
% Correct
Pretest % Right
Post test % Right
13
30
31
57
60
61
62
69
73
74
75
76
77
Question Numbers

In Chapter 3 (Chart 14) shows there was overall improvement recognizing and using the calorie as a heat unit and understanding the meaning of specific heat and processing calorimetry problems.

Questions 8 and 21 showed improvement in recognizing thermal equilibrium and energy. Questions 22, 64, 67 and 70 show small improvements understanding specific heat while question 35 showed a large gain in students' ability to solve a basic calorimetry problem. Questions 8, 35 and 67 were all addressed with activities and labs, which may account for the large increase in post test scores.

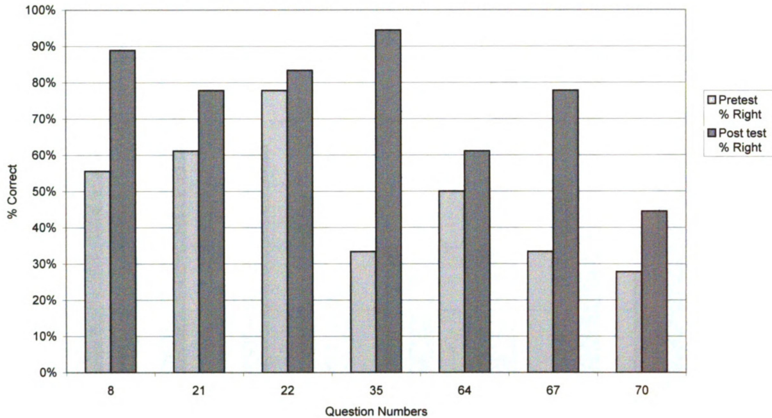
Chapter 4 (Chart 15) was concerned with the mechanical equivalent of heat. Labs were designed to enable the students to establish a relationship between work done and heat energy produced as a result of that work. Students generated evidence that 1 calorie equaled 4.18 Joules. With the exception of question 29 there was excellent improvement from pre to post test performance. In question 29 most students picked foil A which meant that they treated 100 k cal like 100 calories. Questions 42 and 43 again showed big jumps in processing calorimetry problems. Question 15, 34 and 55 pointed to improved qualitative (55) and quantitative (15 and 34) abilities with respect to work and heat.

Questions - Chapter 3

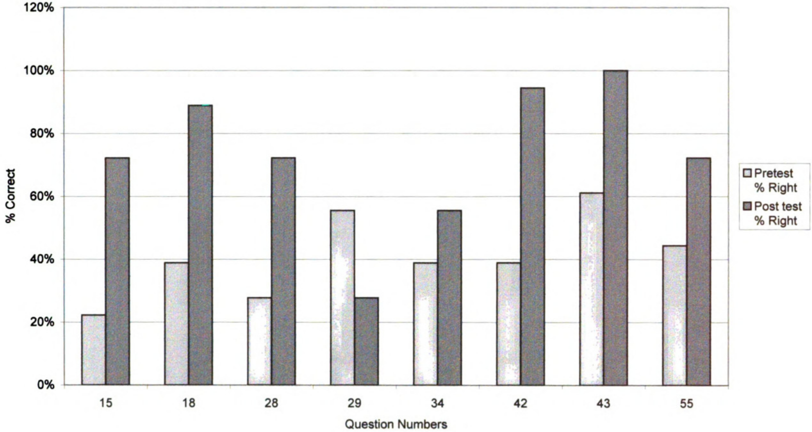
Heat

Pre Test vs Post Test Result Percent Correct of Total Students

Chart 14



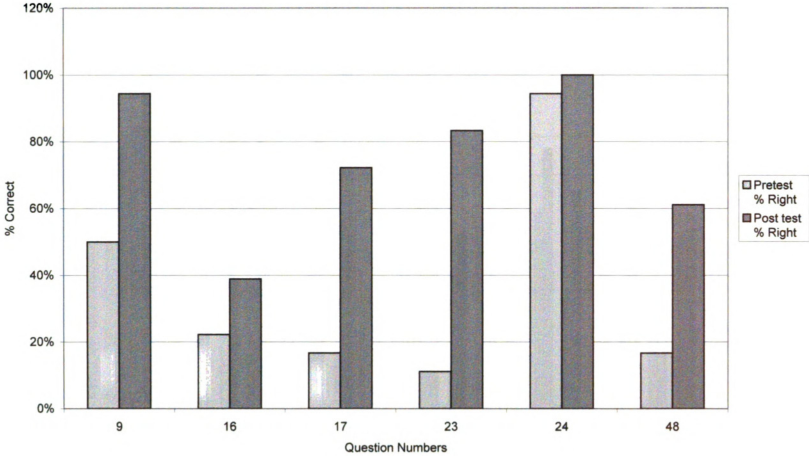
Questions - Chapter 4
Mechanical Equivalent of Heat
Pre Test vs Post Test Result Percent Correct of Total Students
Chart 15



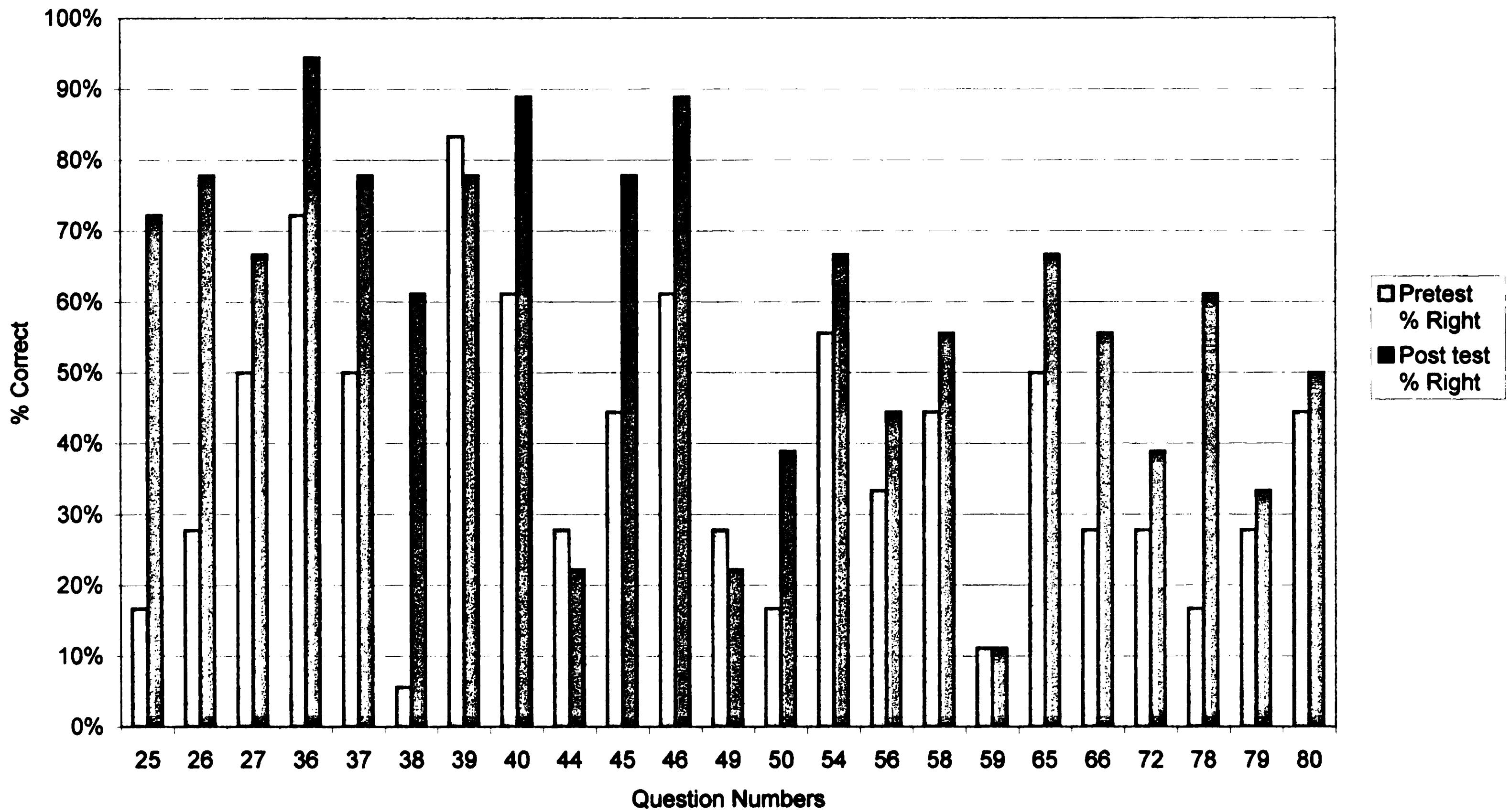
Chapter 5 (Chart 16) investigations used calorimetry techniques to solve for specific heat, equilibrium temperatures and the change in temperature (ΔT). Responses to questions 9 and 24 showed a firm understanding of thermal equilibrium. Question 16 was harder because the calorimeter had the same specific heat as the water. Question 17 addressed equilibrium temperature in a straight-forward manner. Students' improvement on question 48 was large because they needed to glean information from a phase change graph to calculate the specific heat. Responses to question 23 showed students know water has a high specific heat compared to other materials.

Chapter 6 (Chart 17) focuses on phase changes, heat of fusion and heat of vaporization. A glance at the figure shows larger gains in the multiple choice section (with the exception of questions 44 and 49) compared to the modest gains in the short answer section with the exception of question 59. Low scores on question 44 suggest that the definition of the heat of fusion was not firmly in place. Question 49 also addressed the definition in terms of an increase in E_p at 0°C. This knowledge was also not in place. Correct responses to question 59 meant that the students understood that internal energy was the sum of all the energy. There is overall evidence of growth in understanding these phenomena.

Questions - Chapter 5
Calorimetry
Pre Test vs. Post Test Result Percent Correct of Total Students
Chart 16

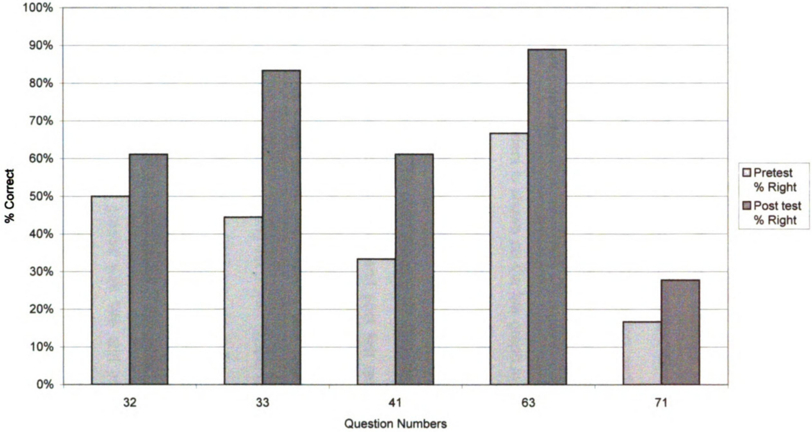


Questions - Chapter 6
Heat of Fusion, Vaporization
Pre Test vs Post Test Result Percent Correct of Total Students
Chart 17



The questions related to Chapter 7 (Chart 18) reflected gain in knowledge with respect to expansion. Questions 32, 33, and 41 showed improvement in the students' ability to solve expansion problems and relate this information to the coefficient of linear expansion. Reponses to question 63 showed an improvement in understanding the role of expansion in freeze/thaw or frost heaving situations. Question 71 used the term bimetallic strip, which was inadvertently not used in discussion or demonstrated in class.

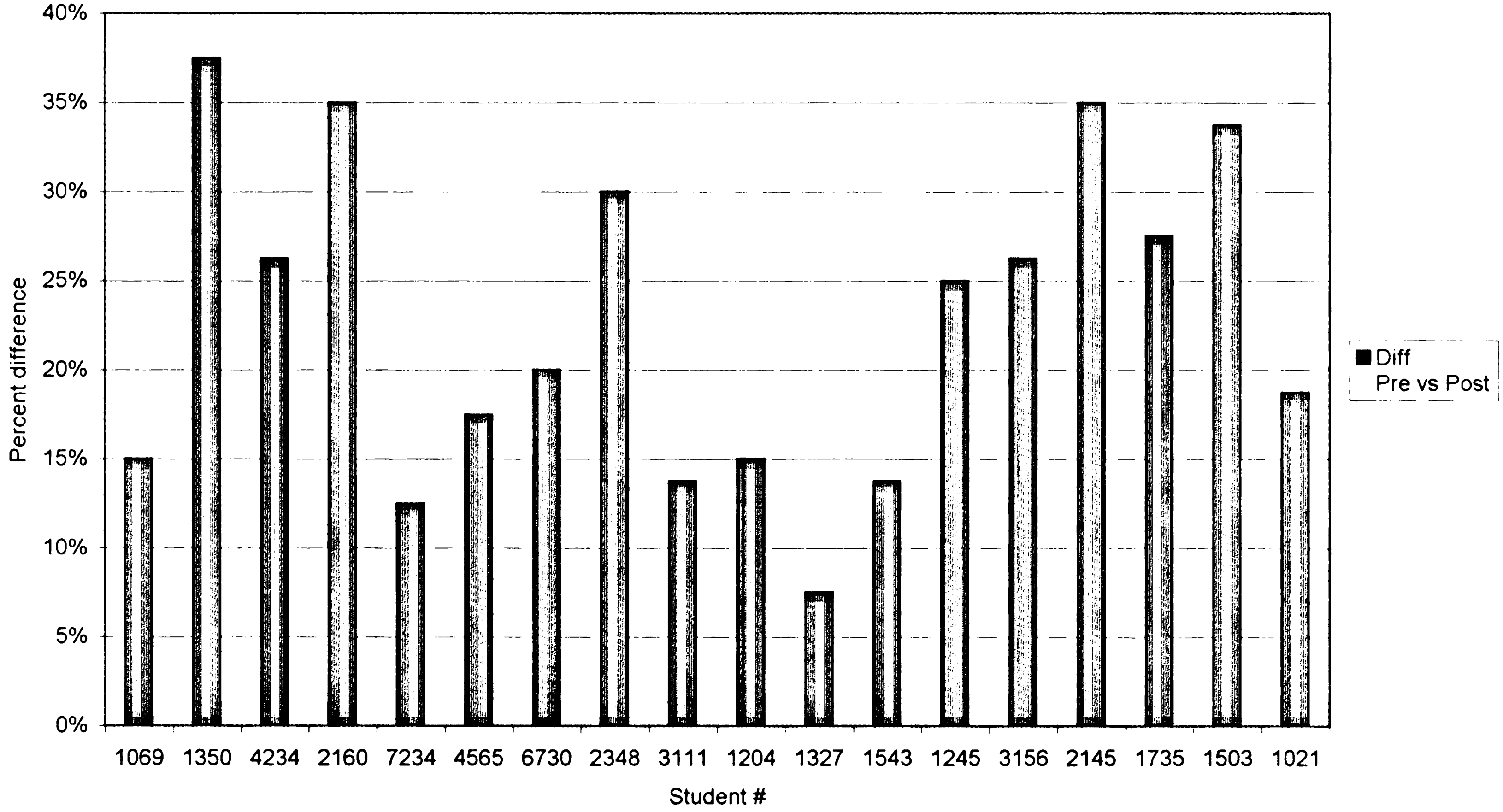
Questions - Chapter 7
Expansion
Pre Test vs Post Test Result Percent Correct of Total Students
Chart 18



Assessment of Chapter 1 showed the best prior knowledge and highest post test scores (59.4% to 80.6%. Chapter 5 reflected the lowest prior knowledge and greatest gain (39.8%). This knowledge is related to labs 13, 14 and 15 dealing with the most involved calorimetry. Chapters 2 and 6 illustrated little prior knowledge and the least gain of all the chapters. Assessment of Chapter 2, dealing with heat transfer, process of conduction, convection and radiation showed improvement. Scores show evidence of improvement for each student in a large majority of the work completed.

Analysis of data for each student is shown on the bar graph in Appendix A. These charts provide individual student data sequentially for the control questions and the questions for each chapter. The overall pre and post test gain for each student is shown on Chart 19. The chart shows eight students produced modest gains of 8% to 18% when comparing pre and post test results. Ten students showed gains from 20% to 38%. Results of student testing produced P-values verified that based on T-test values improvement was related to the amount of effort the student exhibited in completing the project (Appendix A). The students showed the following patterns. Student 1245 brought in the most prior knowledge and was able to generate a 25% gain. On the other hand student 1327 showed very little pre and post test gain as a result of the project. A look at the grade book showed most of the work graded was late and incomplete. Student 1350 brought in a fair amount of prior knowledge to the heat unit and made a 38% gain as a result of the project. Individual student data is available in Appendix A.

Chart 19
Difference
Pre vs Post



Student data in Appendix A showed the majority of students showed modest (10-20%) or significant (20-38%) gain in their ability to answer the post test questions. This gain suggests exposure to the activities and lab experiments helped them acquire more knowledge about heat exchange and heat transfer.

Discussion and Conclusion

Observations made on a daily basis spoke to a changed learning environment. The activity/lab approach created situations that allowed students to study in a more enjoyable atmosphere. It was obvious students enjoyed the labs and activities while they worked cooperatively in small groups. Their self-worth improved as they took pride in and ownership of the results of their investigations. The relaxed atmosphere produced a community of learners who progressed through a large volume of material together, helping one another along the way

There is a good correlation between individual student progress as shown by their pre and post test and compared to their laboratory and homework grades. However, eight students showed limited improvement during this project (8 to 19% improvement). Students 7234, 4565, 6730, 3111, 1204, 1327,. 1543 and 1021 (Appendix A) generally exhibited the following characteristics. Their lab reports were at times incomplete, usually lacking sample calculations and complete conclusions. Most of these students were not good problem solvers (math phobic) and had problems processing data from lab investigations and from homework problems that required a similar effort.

Additionally, six of the eight of these students were paired with one another and had additional problems because neither one was preparing for the labs in advance. This produced problems following proper procedure, which necessitated the need for more trials, which resulted many times in incomplete data collection and lab reports. Student 1069 produced a modest gain of 15% after doing an excellent job in all aspects of the lab work. This student's data was the only anomaly, which reflects his/her ability to take tests.

The remaining members of the class showed higher gains (20-38%) as a result of their involvement in the project. The majority of these students started with higher levels of prior knowledge on the majority of the chapter material. This may have been due to their exposure to a heat section in Chemistry class. Daily observation verified these students were familiar with procedures prior to the lab, which allowed the collection of meaningful data. They could provide direction to their lab partners and others in the lab, process their data quickly to gauge early success and were able to relate lab processes to similar homework problem solving. Their willingness to prepare was one factor that improved their performance. Additionally, from a subjective perspective, they were also highly motivated, successful students with high aspiration levels, they expected to succeed and worked hard to meet their personal expectations. They also exhibited self-control, direction and focus, which helped insure their success in this project. The data on pre-post tests speaks to their overall larger gains in mastering the material in each chapter.

The goal for this project addressed getting away from an objectivist/behaviorist teacher directed environment and developing a place where students could interact with phenomena and directly experience the Physics. Although the project was overly ambitious in terms of activities and labs that were completed, the students responded well in the new environment. They performed well in situations where they needed to construct their own learning, worked well together accomplishing activity and lab investigations and reported their results in a timely manner. Student progress was reflected individually and collectively in the hard evidence presented in the pre/post test results. Conversations with students during the project indicated most students felt the new approach gave them an advantage based on their learning style. Overall the project was a positive experience for student and teacher.

Although the overall impact of the unit was positive, there were some negative aspects. There was too much material (activities and lab reports) and not enough time to discuss each investigation in detail. All the work done on conduction, convection and radiation did not produce the expected gains. There should have been more discussion after the activities were completed on the topics heats of fusion and vaporization, which were difficult which may have been a readiness situation with individual students. Some students were not able to understand the abstract nature of an increase/decrease in potential energy.

Some ideas that seemed to facilitate the project included providing the students with 3-ring notebooks, an envelope file folder and a lab notebook to help organize the activities and labs. The photo/movie record of daily activity was also a positive. Changing from lab notebooks to individual lab reports also helped eliminate repetitious writing. Having a teacher free to roam the room and help when needed was a great resource for the students. Students were also free to repeat trials if needed (at times over lunch on their own time) and could investigate, "what-if-I-did-these-questions-if-more-time-was-available".

This large volume of work on a single topic is not a normal event in any classroom. However, the total immersion of students in an active learning environment did produce perspective with respect to placement of this material. Some of the shorter activities could be used in Physical Science to better prepare students for related concepts in Chemistry and Physics. There could also be a division of these investigations between Chemistry and Physics. Chemistry would do more of the calorimetry and phase change investigations while Physics would address heat transfer, expansion and the mechanical equivalent of heat. There are more activities that were developed that could be utilized for demonstrations.

This project generated a lot of reflection on past teaching practices. Although a lot of lab work is already part of most unit activities, the success of this material means even more material will be used in the future. It was very evident that students learn better in an active environment where they can interact with the phenomena and share their ideas in cooperative learning surroundings. Structuring this environment involves commitment to a new process. However, the reward in terms of student improvement is well worth the effort.

APPENDICES

APPENDIX A

Pre-test and Post-test - Temperature, Heat Energy and Heat Transfer

Name____ Date_______________
Hour_____

1. When two bodies of equal mass collide, the total change in momentum
   a. depends on the velocities of the bodies on impact
   b. depends on the angle at which the two bodies collide.
   c. is equal to zero.
   d. depends on the impulse given to each body on impact

2. The path of the earth around the sun is:
   a. a circle
   b. an ellipse
   c. a parabola
   d. an open circle

3. In certain relativistic experiments, it has been shown that
   a. the mass of an object increases as its velocity increases.
   b. mass and weight are equivalent.
   c. potential energy and kinetic energy are the same.
   d. heat is not actually a form of energy.

4. In an electric circuit, which of the following is absolutely necessary?
   a. a fuse
   b. a switch
   c. a complete path
   d. a dry cell

5. If the magnetic domains in a bar of iron are randomly oriented, the iron bar
   a. will be strongly magnetized.
   b. will have a very weak or nonexistent field.
   c. will be repelled by a permanent magnet.
   d. will line up in a north-south direction when suspended by a string.

6. A substance's temperature increases as a direct result of
   a. energy being removed from the particles of the substance.
   b. kinetic energy being added to the particles of the substance.
   c. a change in the number of atoms and molecules in a substance.
   d. a decrease in the volume of the substance.

7. What happens to the internal energy of an ideal gas when it is heated from 0°C to 4°C?
   a. It increases.
   b. It decreases.
   c. It remains constant.
   d. It is impossible to determine.

8. Which of the following best describes the relationship between two systems in thermal equilibrium?
   a. No net energy is exchanged.
   b. The volumes are equal.
   c. The masses are equal.
   d. The velocity is zero.

9. What is the temperature of a system in thermal equilibrium with another system made up of ice and water at 1 atm of pressure?
   a. 0°C
   b. 273 K
   c. 0 K
   d. 100°K

10. All of the following are widely used temperature scales EXCEPT
    a. Kelvin
    b. Fahrenheit
    c. Celsius
    d. Joule

11. If energy is transferred from a table to a block of ice moving across the table, which of the following statements is true?
    a. The table and the ice are at thermal equilibrium.
    b. The ice is cooler than the table.
    c. The ice is no longer 0°C.
    d. Energy is being transferred from the ice to the table.

12. High temperature is related to
    a. low kinetic energy.
    b. high kinetic energy.
    c. no difference in kinetic energy.
    d. zero net energy.

13. The use of fiberglass insulation in the outer walls of a building is intended to minimize energy transfer through what process?
    a. conduction
    b. radiation
    c. convection
    d. vaporization

14. Which of the following is the equivalent of 88°F?
    a. 31°C
    b. 49°C
    c. 56°C
    d. 160°C

15. What is the temperature increase of water per gram at the bottom of a 145 m waterfall if all of the initial potential energy is transferred as heat to the water? ($g = 9.81\ m/s^2$ and $c_p = 4.19\ J/g \cdot °C$).
    a. 0.170°C
    b. 0.340°C
    c. 0.680°C
    d. 1.04°C

16. A 200 g mass of metal with a specific heat capacity of 1.26 J/g · °C and an initial temperature of 90°C is placed in a 500 g calorimeter at an initial temperature of 20°C with a specific heat capacity of 4.19 J/g·°C. The calorimeter is filled with 100 g of water with an initial temperature of 20°C. When the combination of the metal, the calorimeter, and the water reaches equilibrium, what is the final temperature?
    a. 70°C
    b. 60°C
    c. 50°C
    d. 40°C

17. Find the final equilibrium temperature when 10.0 g of milk at 10.0°C is added to 1.60 x 10^2 g of coffee at a temperature of 90.0°C. Assume the specific heats of coffee and milk are the same for water (c_w = 4.19 J/g·°C) and disregard the heat capacity of the container.
    a. 85.3°C
    b. 77.7°C
    c. 71.4°C
    d. 66.7°C

18. Heat is a physical quantity most closely related to
    a. temperature.
    b. friction.
    c. energy.
    d. momentum

19. Two thermometers, one calibrated in the Celsius scale and the other in the Fahrenheit scale, are used to measure the same temperature. The numerical reading on the Fahrenheit thermometer
    a. is proportional to that on the Celsius thermometer.
    b. is greater than that on the Celsius thermometer.
    c. is less than that on the Celsius thermometer.
    d. may be greater or less than that on the Celsius thermometer.

20. A temperature of 100°F is almost exactly
    a. 38°C
    b. 122°C
    c. 56°C
    d. 212°C

21. Two blocks of lead, one twice as heavy as the other, are both at 50°C. The ratio of the internal energy content of the heavier block to that of the lighter block is
    a. ½
    b. 2
    c. 1
    d. 4

22. The quantity of heat required to change the temperature of a unit amount of a substance by 1° is called its
    a. specific heat capacity.
    b. heat of fusion .
    c. heat of vaporization.
    d. mechanical equivalent of heat.

23. Of the following substances, the one which requires the greatest amount of heat per kg for a given increase in temperature is
    a. ice
    b. water
    c. steam
    d. copper

24. Body *A* is at a higher temperature than body *B*. When they are placed in contact, heat will flow from *A* to *B*
    a. only if *A* has the greater internal energy content.
    b. only if both are fluids.
    c. only if *A* is on top of *B*.
    d. until both have the same temperature.

25. When a vapor condenses into a liquid,
    a. it absorbs heat.
    b. it evolves heat.
    c. its temperature rises.
    d. its temperature drops.

26. The heat of vaporization of a substance is
    a. less than its heat of fusion.
    b. equal to its heat of fusion.
    c. greater than its heat of fusion.
    d. any of the above, depending on the nature of the substance.

27. The freezing point of a substance is always lower than its
    a. melting point.
    b. boiling point.
    c. heat of fusion.
    d. heat of vaporization.

28. The ratio between the energy dissipated in some process and the heat that appears as a result is called the
    a. Joule.
    b. kilocalorie.
    c. specific heat capacity.
    d. mechanical equivalent of heat.

29. A 61-kg woman eats a banana whose energy content is 100 kcal. If this energy were used to raise her from the ground, her approximate height would be

a. 0.7 m
b. 70 m
c. 7 m
d. 700 m

30. If a threaded metal lid on a glass jar is stuck, probably the safest method of unscrewing the lid is to first

a. place the whole jar in boiling water.
b. place the whole jar in the freezing compartment of a refrigerator.
c. pack the lid with a bag of ice.
d. put only the lid in hot water.

31. In a deep, freshwater pond in winter when the air temperature is –10°C

a. the water at the bottom is about 4°C.
b. the ice on the surface is at 2°C.
c. the temperature of the water is the same at all levels under the ice.
d. the coldest water is at the bottom.

32. Which material would expand the least when heated?

a. W, $\alpha = 24 \times 10^{-6}/°C$
b. X, $\alpha = 17 \times 10^{-6}/°C$
c. Y, $\alpha = 10 \times 10^{-6}/°C$
d. Z, $\alpha = 3 \times 10^{-6}/°C$

33. A cast-iron pipe 300 m long is heated from –10°C to 150°C. What is the change in length of the pipe? ($\alpha = 11 \times 10^{-6}/°C$)

a. 4.80 m
b. 0.528 m
c. 52.8m
d. 5.28 m

34. A heavy crate is pushed along a concrete floor a distance of 50.0 m. If the force of friction is 15.0 N, the heat produced is:

a. 180 cal
b. 1.80 cal
c. 0.792 cal
d. 3.12×10^{-3}

35. How much heat is needed to raise the temperature of a 200-g block of aluminum from 20.0°C to the boiling point of water? (*c* of aluminum = 0.210 cal/g·°C)

a. 1.60×10^{4}cal
b. 3.36×10^{3}cal
c. 7.62×10^{4}cal
d. 3.78×10^{3}cal

36. In conducting an investigation on how much heat is absorbed by the melting of ice, you use a calorimeter, beakers, ice cubes, a thermometer and a laboratory balance. Which of the following might be a source of error?
    a. Ice cubes are placed in the calorimeter with drops of water on them.
    b. The warm water in the calorimeter cup is at 25°C.
    c. The ice cubes are at exactly 0°C.
    d. The warm water and ice cubes were stirred in the calorimeter cup.

37. Which of the following statements about the heat of fusion is correct?
    a. The symbol for heat of fusion is ΔQ.
    b. Heat of fusion is the amount of heat absorbed when a unit mass of a solid melts without change in temperature.
    c. Heat of fusion is measured in N/cm^2.
    d. The heat of fusion is the change in temperature of a substance when it freezes or melts.

38. If 2.0 kg of ice are used to chill some cans of soft drink and the ice melts completely, how much heat does the ice absorb? (Assume that the temperature of the ice water does not change.)
    a. 160 cal
    b. 16 cal
    c. 16×10^4 cal
    d. 16×10^3 cal

Use the following table to answer Question 39

Liquid	Heat of vaporization (cal/g)
A	46
B	204
C	263
D	540

39. Which liquid is best to use as a coolant in automobile engines?
    a. A
    b. B
    c. C
    d. D

40. Water boils at lower temperatures at high altitudes because
    a. the water is in dynamic equilibrium with the air.
    b. when the pressure of air is reduced, the molecules of water can more easily escape.
    c. molecules of water require more energy to become gas molecules at reduced pressure.
    d. the speed of water molecules is reduced.

41. A copper rod 1.0 m long increases in length 1.7×10^{-5} m when heated 1.0°C. If a copper rod 100.0 m long at 20.0 °C is heated to 50°C what will be the increase in length in cm?
   a. 5.10 cm
   b. 51 cm
   c. 0.l051 cm
   d. 510 cm

42. How many calories are needed to raise the temperature of 300 g of water from 10°C to 100°C?
   a. 3.0×10^5 cal
   b. 27 cal
   c. 270 cal
   d. 2.7×10^4cal

43. How much heat is required to raise the temperature of a 50-g ball of cast-iron from 10°C to 80°C? (*c* of cast-iron = 0.12 cal/g· °C)
   a. 3.5×10^3 cal
   b. 4.2 cal
   c. 4.2×10^2 cal
   d. 4.2×10^3 cal

44. The heat of fusion for water is about 80 cal/g. This statement is the same as saying that
   a. when ice melts, it gains heat energy.
   b. when ice receives heat energy, the molecules speed up.
   c. when ice melts, it changes temperature.
   d. heat is absorbed by melting ice without a temperature change.

45. How much heat is needed to melt 0.5 kg of copper? (heat of fusion of copper = 49 cal/g)
   a. 2.4×10^2 cal
   b. 2.4×10^4 cal
   c. 24 cal
   d. 2.4×10^3 cal

46. Swimmers feel cool when they get out of the water, even though the air is warmer than the water because
   a. all water molecules have the same speed.
   b. the forces attracting water molecules together become stronger.
   c. water molecules gain heat in the process of evaporation.
   d. water molecules only evaporate at the boiling point.

47. An amateur explorer in the Arctic reported that the temperature of ice deep in a glacier was –280°C. You know this statement is incorrect because
    a. ice cannot be colder than 0°C.
    b. the explorer was not a scientist.
    c. absolute zero is –273°C.
    d. there are no glaciers in the Arctic.

1 10-g solid is completely melted in a well-insulated calorimeter, using a heat source that delivers 100 cal/min. (Assume no heat is transferred to the calorimeter.) Use the heating curve of the substance to answer Questions 48-50. The heating curve is on a separate piece of paper.

48. The specific heat capacity of the solid in cal/g·C is approximately:
    a. 0.50
    b. 0.57
    c. 1.7
    d. 1.8

49. Between 2.0 minutes and 6.0 minutes,
    a. the heat source was turned off.
    b. the kinetic energy of the molecules increased.
    c. the potential energy of the molecules increased.
    d. the internal energy of the substance is unchanged.

50. The heat of fusion of the substance is:
    a. 6.0×10^2 cal/g
    b. 4.0×10^2 cal/g
    c. 40 cal/g
    d. 20 cal/g.

51-80 are short answer questions (Answers may be completed with 2-3 sentences)

51. The speed of a ball increases as it rolls down an incline and decreases as it rolls up an incline. What happens to its speed on a smooth, horizontal surface?

52. What did Newton discuss about gravity?

53. What does it mean to say the speed of light is constant?

54. How does perspiration give the body a means of cooling itself?

55. A jar of water is shaken vigorously. What becomes of the work that is done?

56. Which is more effective in cooling a drink, 10 g of water at 0°C or 10 g of ice at 0°C? Why?

57. Why would covering most of the body keep a person cool in the desert?

58. Why does turning the flame higher under a pan of boiling water not reduce the time needed to cook an egg in the water?

59. When a certain quantity of vapor condenses into a liquid, what happens to its internal energy content and to its temperature?

60. What is the principal means of heat transfer from a hot object to a cold object when they are separated by:
   a. a vacuum?
   b. a solid metal?
   c. A gas when the warmer object is beneath the cooler object?

Pre-test and Post-test - Temperature, Heat Energy and Heat Transfer

61. What method of heat transfer is used to heat the upstairs of a house with a furnace in the basement?

62. How is heat transfer from the sun to the earth accomplished?

63. The phase change from water to ice can lead to the cracking of rocks and the destruction of highways. Explain.

64. Ethyl alcohol has about one half the specific heat of water. If equal masses of alcohol and water in separate beakers are supplied with the same amount of heat, compare the temperature increases of the two liquids.

65. In a daring lecture demonstration, an instructor dips her wetted fingers into molten lead (327°C) and withdraws them quickly without getting burned. How is this possible?

66. Why can you get a more severe burn from steam at 100°C than from water at 100°C?

67. If you hold water in a paper cup over a flame, you can bring the water to a boil without burning the cup. How is this possible?

68. How many degrees are between the melting point of ice and boiling point of water on the Celsius scale? Fahrenheit scale?

69. In terms of differences in temperature between objects in thermal contact, in what direction does heat flow?

70. What does it mean to say that a material has a high or low specific heat capacity?

71. Why does a bimetallic strip curve when it is heated (or cooled)?

72. Why do lakes and ponds freeze from the top down rather than from the bottom up?

73. What is the role of "loose" electrons in heat conductors?

74. Why are materials such as wood, fur, feathers and even snow good insulators?

75. Dominoes are placed upright in a row, one next to another. When one is tipped over, it knocks against its neighbor, which does the same in cascade fashion until the whole row collapses. Which of the three types of heat transfer is this most similar to?

76. Which will normally cool faster, a black pot of hot tea or a silver pot of hot tea?

77. Which will undergo the greater rate of cooling, a red-hot poker in a warm oven or a red-hot poker in a cold room (or do both cool at the same rate)?

78. What is evaporation and why is it also a cooling process?

79. Why is being burned by steam more damaging than being burned by boiling water of the same temperature?

80. What is the difference between evaporation and boiling?

Student Survey: The Effectiveness of heat Transfer-Heat Exchange Unit

		1	2	3	4	5
#	Statement	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1	Prior to this unit I did not know much about heat or heat transfer	50%	8%	25%	17%	0%
2	The Laboratory activities help me better understand the topic under investigation	83%	17%	0%	0%	0%
3	The labs were specific with respect to topic and helped with associated problem solving.	42%	58%	0%	0%	0%
4	The labs were interesting and fun.	42%	58%	0%	0%	0%
5	The labs were well organized.	42%	33%	25%	0%	0%
6	The labs made the topics easier to understand.	67%	33%	0%	0%	0%

7	The lab analysis, questions and conclusions made me think about the investigation.	33%	33%	17%	17%	0%
8	The labs were reasonably easy to follow.	33%	58%	8%	0%	0%
9	Interaction with my partner and group activities made me a more responsible person.	42%	17%	33%	8%	0%
10	I became a better writer as a result of these lab activities.	8%	50%	42%	0%	0%
11	The objective of the lab allowed me to see how the process followed would produce an outcome.	58%	33%	8%	0%	0%
12	The introduction and background information provided with some of the labs heloped me understand the process.	50%	8%	33%	0%	8%
13	Learning by doing does not always make everything immediately clear but helps me better understand that part of the topic.	58%	25%	17%	0%	0%
14	This approach and its multivaried activities were of value to my learning style.	67%	42%	0%	0%	0%

Student Surveys

What could be done to improve these activities?

1 More testing and quizing over the material mixed in between the labs.
2 More notes on the experiment after it is completed.
3 Slow down. Discuss the activities more.
4 Too much repetition (calorimetry)
5 Write out full lab reports using worksheets as guides.
6 More time to complete additional trials.
7 More prep time in class and more diagrams on lab sheets.

8 Give students more background information before we do the experiment.

Comments:

1 Enjoyed the experiments. Labs and activities helped me grasp the contents.
2 The lab sequence was good.
3 The labs and activites related well to the homework.
4 With the hands on approach I was able to see what was happening. This made the activities more enjoyable.
5 I was lazy doing the lab reports in a timely manner.
6 Need to develop a completely different technique for the expansion of solids. Measuring rods was boring.
7 Need to slow down and discuss the activities in more depth.
8 Enjoyed the variety of labs. There was always something new.
9 Needed more testing and quizing after lab work was completed.
10 Enjoyed working in cooperative situations.
11 Became aware of the value of making precise measurements in the lab.
12 My writing improved as a result of all the work done summarizing the labs.
13 The majority of the people seemed to be having a lot of fun.

t-Test: Two-Sample Assuming Equal Variances		
Chapter 1 Pre vs. Post T-Test		
	Variable 1	*Variable 2*
Mean	5.94E-01	8.06E-01
Variance	6.93E-02	4.96E-02
Observations	1.00E+01	1.00E+01
Pooled Variance	5.94E-02	
Hypothesized Mean Difference	0.00E+00	
df	1.80E+01	
t Stat	-1.94E+00	
P(T<=t) one-tail	3.43E-02	
t Critical one-tail	1.73E+00	
P(T<=t) two-tail	6.87E-02	
t Critical two-tail	2.10E+00	
t-Test: Two-Sample Assuming Equal Variances		
Chapter 2 Pre vs. Post Test		
	Variable 1	*Variable 2*
Mean	3.63E-01	5.98E-01
Variance	3.43E-02	6.03E-02
Observations	1.30E+01	1.30E+01
Pooled Variance	4.73E-02	
Hypothesized Mean Difference	0.00E+00	
df	2.40E+01	
t Stat	-2.76E+00	
P(T<=t) one-tail	5.49E-03	
t Critical one-tail	1.71E+00	
P(T<=t) two-tail	1.10E-02	
t Critical two-tail	2.06E+00	
t-Test: Two-Sample Assuming Equal Variances		
Chapter 3 Pre vs. Post Test		
	Variable 1	*Variable 2*
Mean	4.84E-01	7.54E-01
Variance	3.26E-02	2.97E-02
Observations	7.00E+00	7.00E+00
Pooled Variance	3.12E-02	
Hypothesized Mean Difference	0.00E+00	
df	1.20E+01	
t Stat	-2.86E+00	
P(T<=t) one-tail	7.18E-03	
t Critical one-tail	1.78E+00	
P(T<=t) two-tail	1.44E-02	
t Critical two-tail	2.18E+00	P

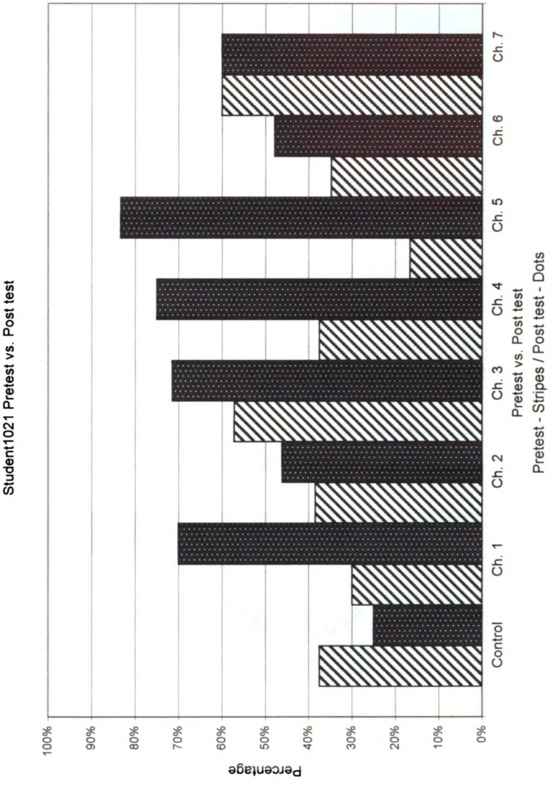
t-Test: Two-Sample Assuming Equal Variances Chapter 4 - Pre vs. Posttest		
	Variable 1	*Variable 2*
Mean	4.10E-01	7.29E-01
Variance	1.67E-02	5.42E-02
Observations	8.00E+00	8.00E+00
Pooled Variance	3.54E-02	
Hypothesized Mean Difference	0.00E+00	
df	1.40E+01	
t Stat	-3.39E+00	
P(T<=t) one-tail	2.18E-03	
t Critical one-tail	1.76E+00	
P(T<=t) two-tail	4.37E-03	
t Critical two-tail	2.14E+00	

t-Test: Two-Sample Assuming Equal Variances Chapter 5 - Pre vs. Posttest		
	Variable 1	*Variable 2*
Mean	3.52E-01	7.50E-01
Variance	1.03E-01	5.15E-02
Observations	6.00E+00	6.00E+00
Pooled Variance	7.74E-02	
Hypothesized Mean Difference	0.00E+00	
df	1.00E+01	
t Stat	-2.48E+00	
P(T<=t) one-tail	1.63E-02	
t Critical one-tail	1.81E+00	
P(T<=t) two-tail	3.26E-02	
t Critical two-tail	2.23E+00	

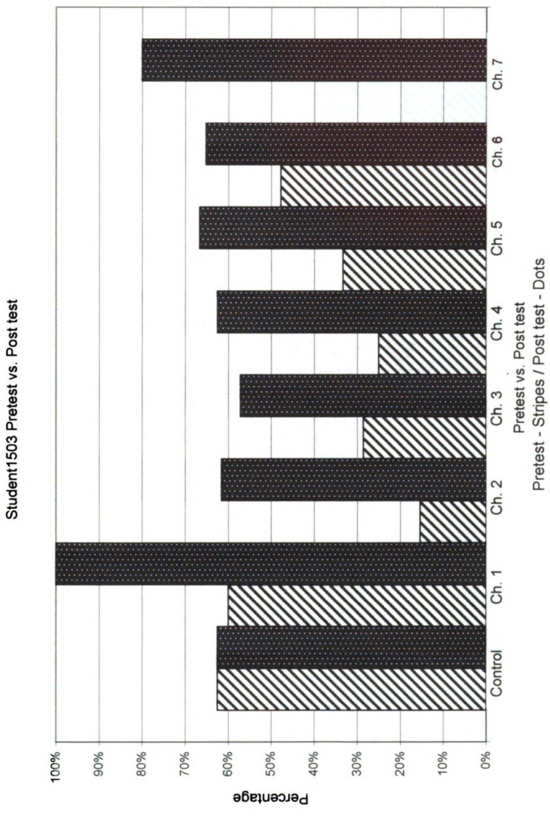
t-Test: Two-Sample Assuming Equal Variances Chapter 6 - Pre vs. Posttest		
	Variable 1	*Variable 2*
Mean	3.84E-01	5.87E-01
Variance	4.07E-02	5.27E-02
Observations	2.30E+01	2.30E+01
Pooled Variance	4.67E-02	
Hypothesized Mean Difference	0.00E+00	
df	4.40E+01	
t Stat	-3.18E+00	
P(T<=t) one-tail	1.33E-03	
t Critical one-tail	1.68E+00	
P(T<=t) two-tail	2.66E-03	
t Critical two-tail	2.02E+00	

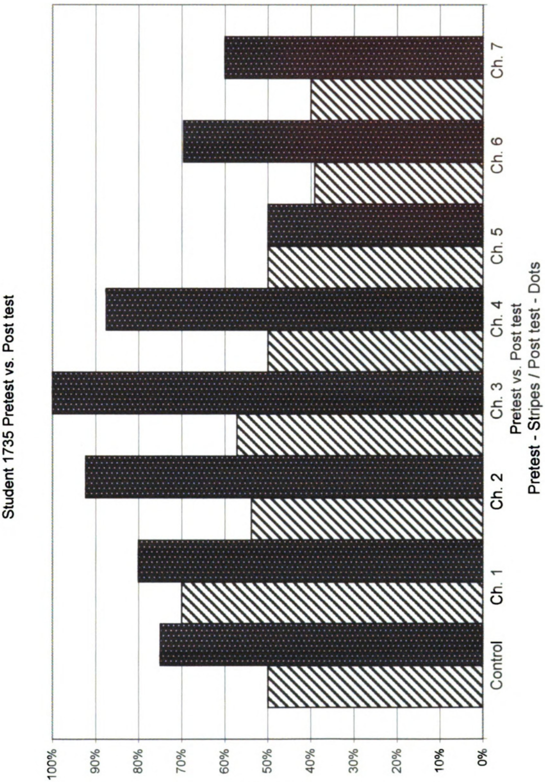
t-Test: Two-Sample Assuming Equal Variances		
Chapter 7 - Pre vs. Posttest		
	Variable 1	*Variable 2*
Mean	4.22E-01	6.44E-01
Variance	3.49E-02	5.80E-02
Observations	5.00E+00	5.00E+00
Pooled Variance	4.65E-02	
Hypothesized Mean Difference	0.00E+00	
df	8.00E+00	
t Stat	-1.63E+00	
P(T<=t) one-tail	7.08E-02	
t Critical one-tail	1.86E+00	
P(T<=t) two-tail	1.42E-01	
t Critical two-tail	2.31E+00	

t-Test: Two-Sample Assuming Equal Variances		
Control - Pre vs. Posttest		
	Variable 1	*Variable 2*
Mean	5.21E-01	5.76E-01
Variance	1.12E-01	7.58E-02
Observations	8.00E+00	8.00E+00
Pooled Variance	9.39E-02	
Hypothesized Mean Difference	0.00E+00	
df	1.40E+01	
t Stat	-3.63E-01	
P(T<=t) one-tail	3.61E-01	
t Critical one-tail	1.76E+00	
P(T<=t) two-tail	7.22E-01	
t Critical two-tail	2.14E+00	

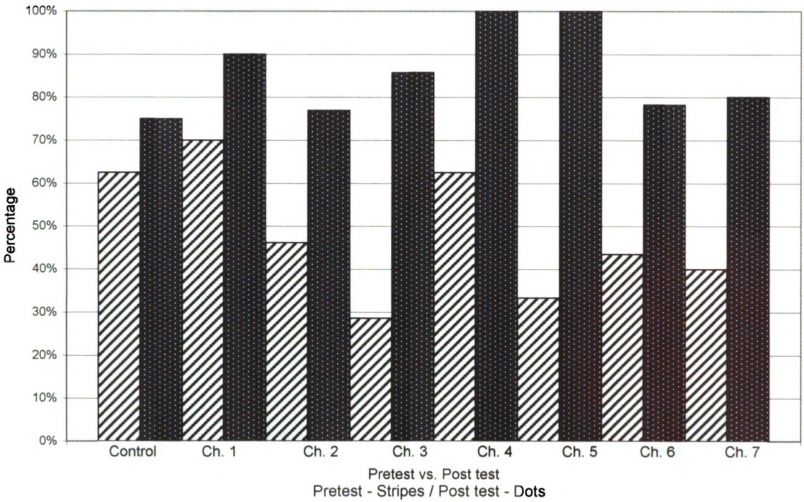


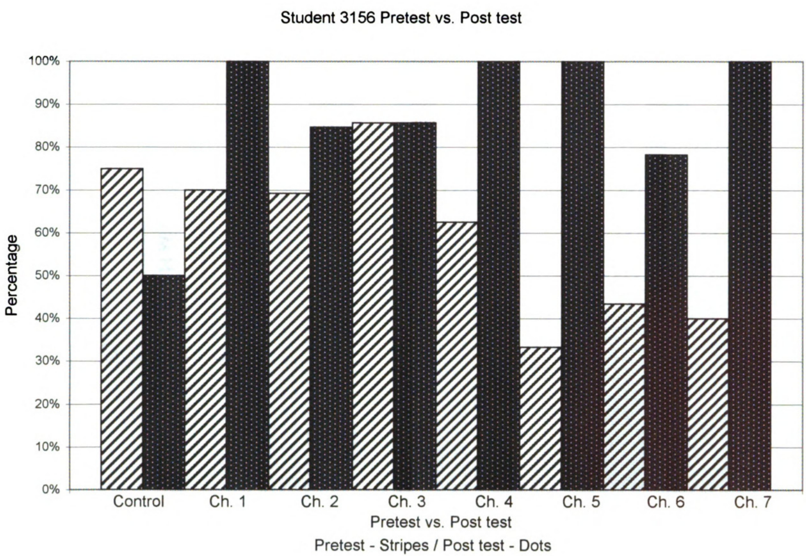
Student1021 Pretest vs. Post test
Percentage
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Control
Ch. 1
Ch. 2
Ch. 3
Ch. 4
Ch. 5
Ch. 6
Ch. 7
Pretest vs. Post test
Pretest - Stripes / Post test - Dots


Student1503 Pretest vs. Post test
Percentage
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Control
Ch. 1
Ch. 2
Ch. 3
Ch. 4
Ch. 5
Ch. 6
Ch. 7
Pretest vs. Post test
Pretest - Stripes / Post test - Dots

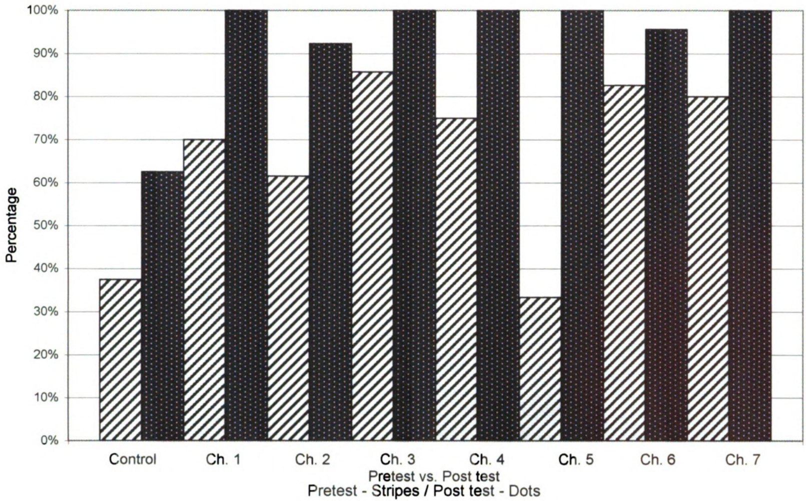

Student 1735 Pretest vs. Post test
Percentage
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Control
Ch. 1
Ch. 2
Ch. 3
Ch. 4
Ch. 5
Ch. 6
Ch. 7
Pretest vs. Post test
Pretest - Stripes / Post test - Dots

Student 2145 Pretest vs. Post test

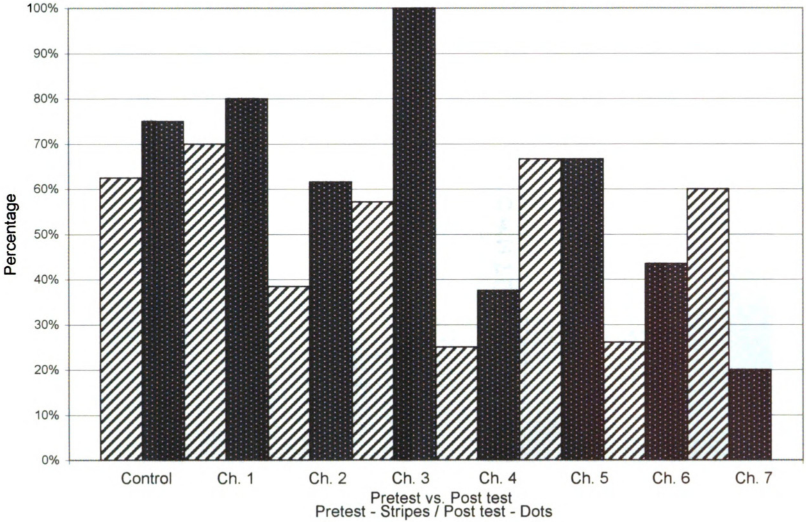


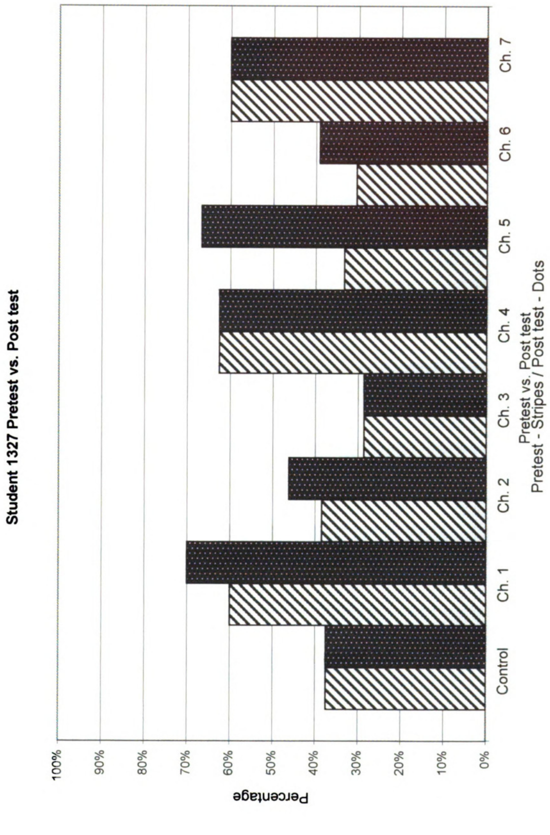

Student 3156 Pretest vs. Post test
Percentage
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Control
Ch. 1
Ch. 2
Ch. 3
Ch. 4
Ch. 5
Ch. 6
Ch. 7
Pretest vs. Post test
Pretest - Stripes / Post test - Dots

Student 1245 Pretest vs. Post test



Student 1543 Pretest vs. Post test

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Percentage
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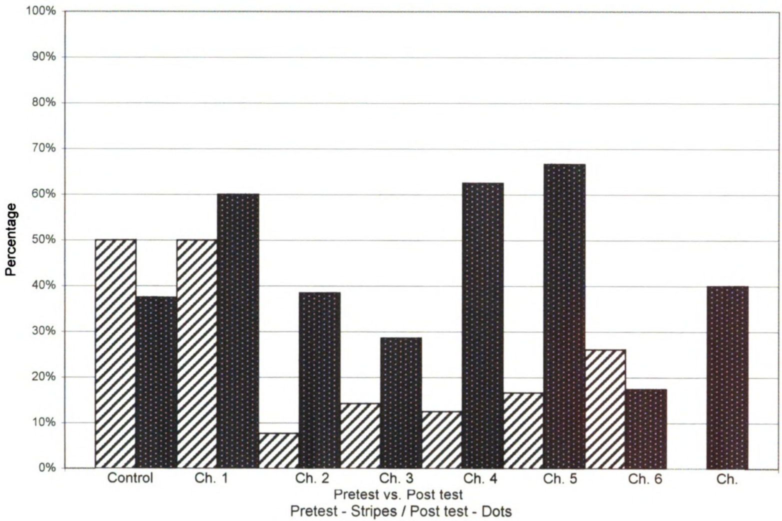
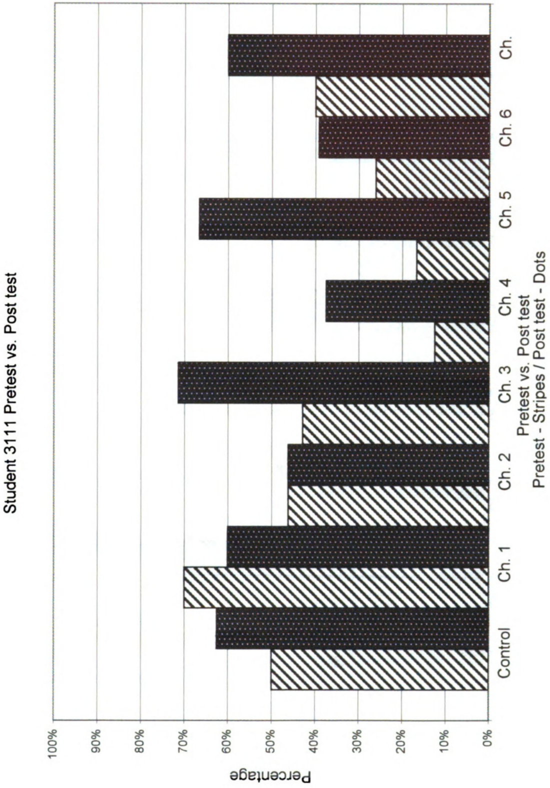
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Control
Ch. 1
Ch. 2
Ch. 3
Ch. 4
Ch. 5
Ch. 6
Ch. 7
Pretest vs. Post test
Pretest - Stripes / Post test - Dots

Student 1204 Pretest vs. Post test

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Percentage
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80%
70%
60%
50%
40%
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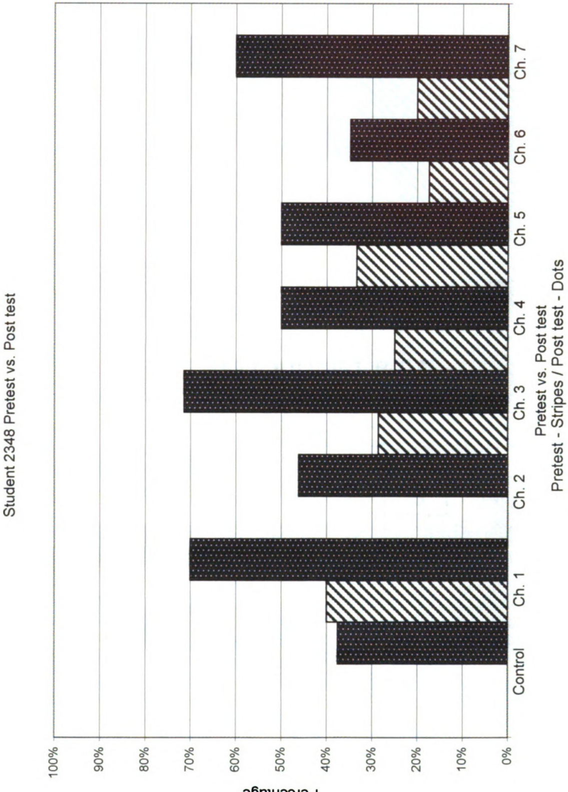
20%
10%
0%
Control
Ch. 1
Ch. 2
Ch. 3
Ch. 4
Ch. 5
Ch. 6
Ch.
Pretest vs. Post test
Pretest - Stripes / Post test - Dots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Percentage
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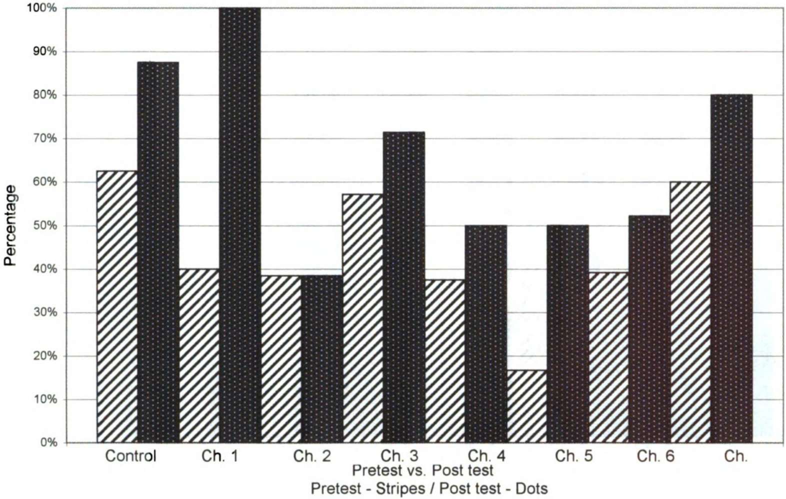
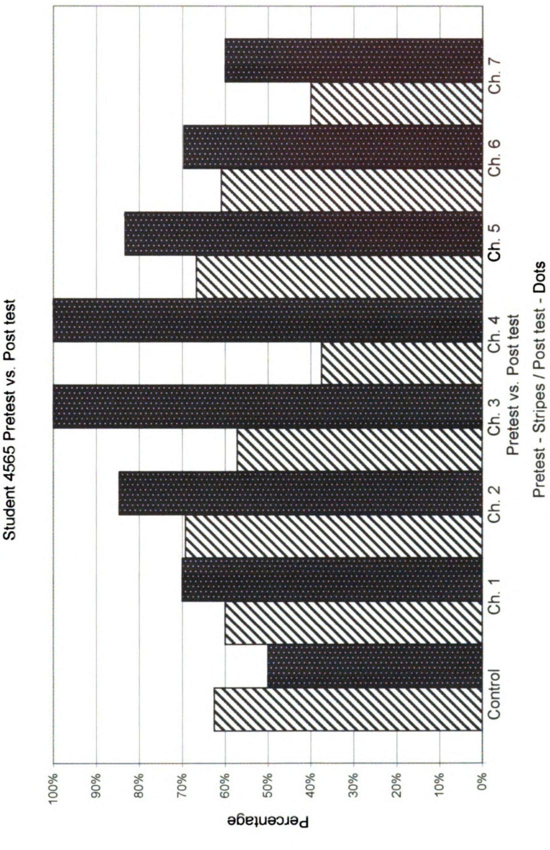
80%
70%
60%
50%
40%
30%
20%
10%
0%
Control
Ch. 1
Ch. 2
Ch. 3
Ch. 4
Ch. 5
Ch. 6
Ch. 7
Pretest vs. Post test
Pretest - Stripes / Post test - Dots

Student 6730 Pretest vs. Post test





Student 4565 Pretest vs. Post test
Percentage
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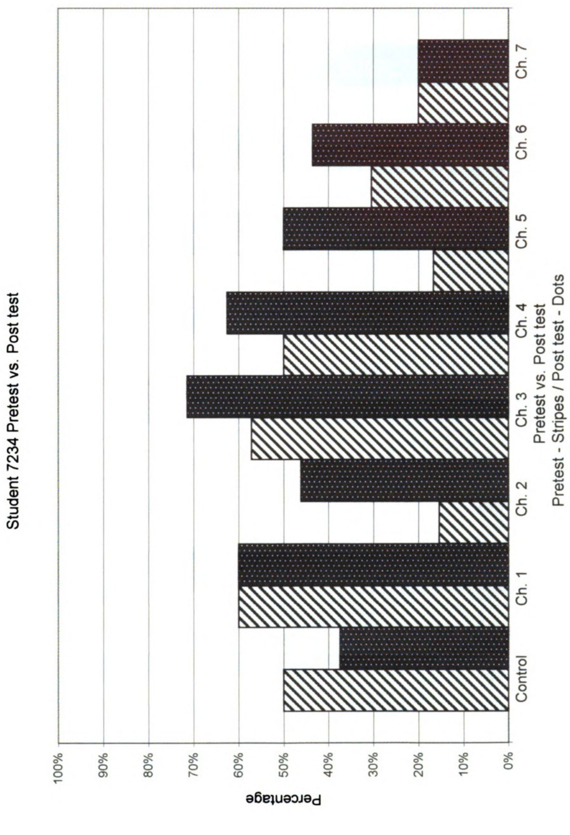
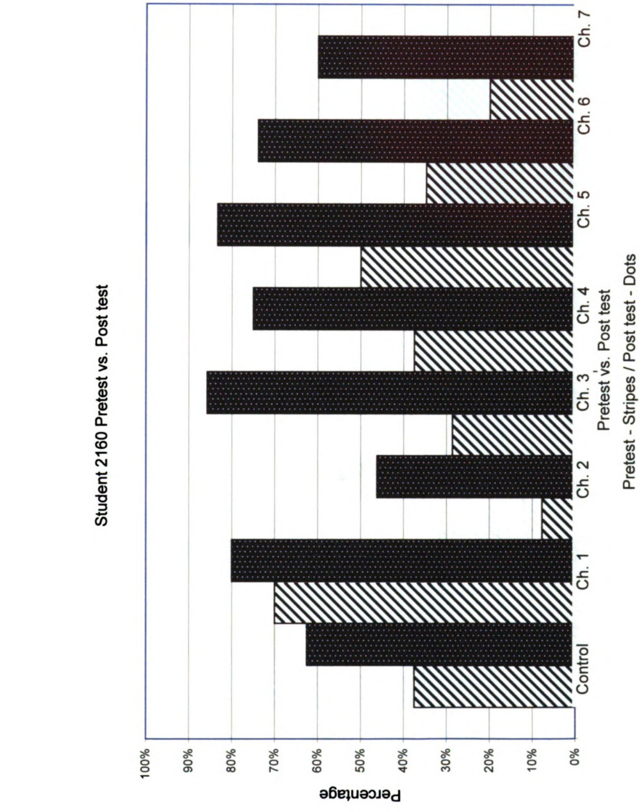
80%
70%
60%
50%
40%
30%
20%
10%
0%
Control
Ch. 1
Ch. 2
Ch. 3
Ch. 4
Ch. 5
Ch. 6
Ch. 7
Pretest vs. Post test
Pretest - Stripes / Post test - Dots


Student 7234 Pretest vs. Post test
Percentage
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Control
Ch. 1
Ch. 2
Ch. 3
Ch. 4
Ch. 5
Ch. 6
Ch. 7
Pretest vs. Post test
Pretest - Stripes / Post test - Dots



Student 2160 Pretest vs. Post test
Percentage
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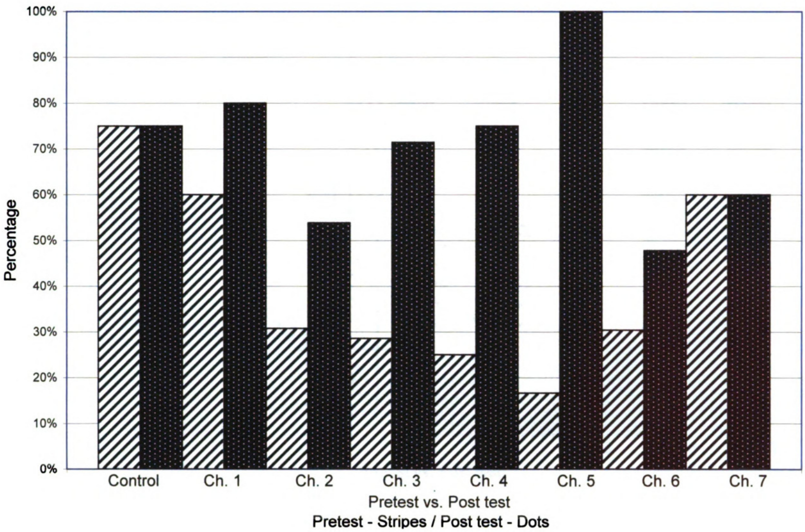
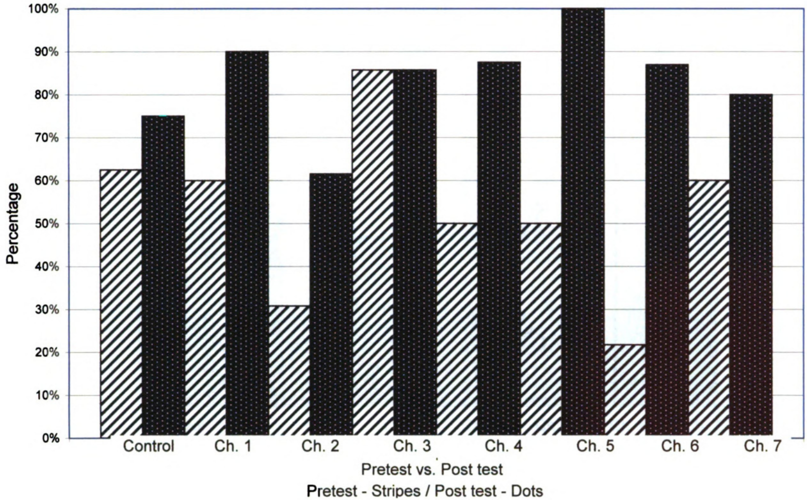
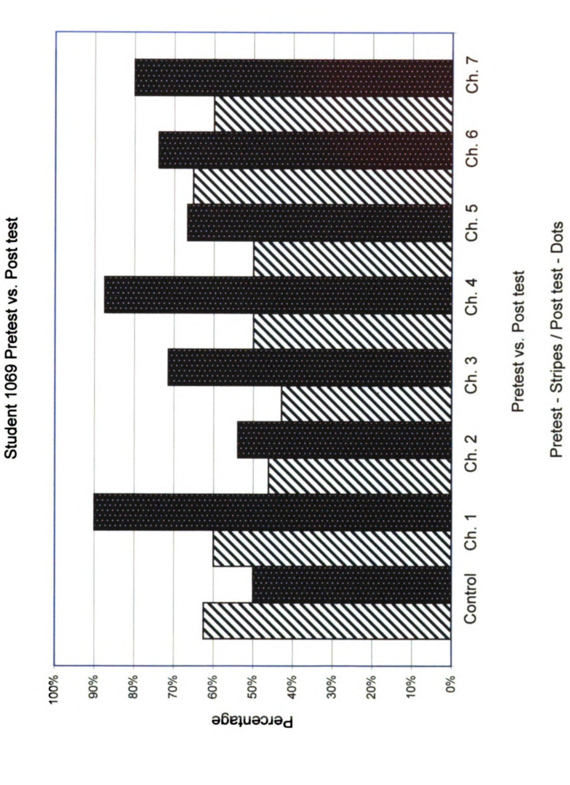
80%
70%
60%
50%
40%
30%
20%
10%
0%
Control
Ch. 1
Ch. 2
Ch. 3
Ch. 4
Ch. 5
Ch. 6
Ch. 7
Pretest vs. Post test
Pretest - Stripes / Post test - Dots

Student 4234 Pretest vs. Post test



Student 1350 Pretest vs. Post test




Student 1069 Pretest vs. Post test
Percentage
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90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Control
Ch. 1
Ch. 2
Ch. 3
Ch. 4
Ch. 5
Ch. 6
Ch. 7
Pretest vs. Post test
Pretest - Stripes / Post test - Dots

APPENDIX B

Background on Heat, Thermal Energy and Temperature

The quantitative study of heat dates from the invention of the calorimeter in 1760. Dr. Joseph Black's calorimeter was a hollow block of ice with a removable top and a thermometer to measure the temperature of samples placed inside. Black's experiments proved a relationship between the ice that melted and the loss of heat by the objects that came into contact with the ice. When he mixed substances in this calorimeter that started out at different temperatures, he found heat to behave as an indestructible fluid. Heat lost by one substance was gained by another until they both reached a common temperature. People already thought heat was an invisible fluid called caloric that flowed from hot to cold and Black's work led to a wide acceptance of caloric theory.

Thirty years later Benjamin Thompson (1753-1814) made experimental observations that suggested caloric was not conserved. Thompson was an American scientist who emigrated to Europe during the Revolutionary War, as he was an English (Tory) sympathizer. He was appointed director of the Bavarian arsenal and given the title of Count Rumford. As a member of the Austrian Army he was in charge of cannon production. He supervised the boring of cannons in Munich. As he managed the production of cannons he wondered why so much heat was generated in the barrels when there was no obvious heat source. The boring tool was cooled with water that was constantly replaced as it boiled away. He became curious, investigated the situation and made the discovery that there is equivalence between heat and mechanical work. Using caloric theory he reasoned the ability of metal filings (produced by the boring tool) to retain caloric should decrease as their size decreased. The heated filings transferred caloric to cooling water and caused it to boil. He therefore, used blunt and sharp tools and found both boiled away the same amount of water. He noticed an infinite amount of heat could be produced with only a small amount of filings. He rejected caloric theory and suggested heat was not a substance but some type of motion transferred from boring tool to the water. He later showed that the heat generated by friction was proportional to the mechanical work done by the boring tool.

One hundred years later the work of Joule (1819-1887), von Mayer (1814-1878) and von Hemholtz (1821-1894) led conclusively that heat is a form of energy. Joule's experiments along with others proved that whenever heat was gained or lost by a system during some process, this gain or loss was related to some equivalent amount of work done on or by the system. Joule wrote the following "Whenever a living force [E_k] is apparently destroyed, whether by percussion, friction or any similar means, an exact equivalent of heat is restored (produced). The converse of this proposition is also true, namely heat cannot be lessened or absorbed without the production of living force, or its equivalent attraction through space [E_p]. Thus, for instance, in the steam engine it will be found that the power gained at the expense of the heat of the fire – that is, that the heat occasioned by the combustion of the coal would have been greater had a part of it not been absorbed in producing and maintaining the living force of the machinery."

Modern day observations revealed that any macroscopic system that is left undisturbed reaches an equilibrium state. Close a room completely to the outside and the heat within the objects in the room will flow from warmer to cooler and eventually reach a state of thermal equilibrium that is characterized by all the objects having the same temperature. This thermal energy was transferred among the objects in the room by three mechanisms conduction, convection and radiation. Conduction involves the transfer of thermal energy by electron or molecular interaction and is a slow process. Convection involves the movement of a portion of a heated fluid from one place to another and is a rapid process. Radiation refers to the emission or absorption of electromagnetic wave that travels at the speed of light.

Thermal energy refers to the energy associated with the random motion (total E_k and E_p) of molecules and atoms and it increases with temperature. There is no precise definition (formula) for thermal energy. However, if we want to be quantitative, the terms heat energy and internal energy can be used.

Internal energy is the sum of all the energy of all the molecules. It is the total of all kinds of energy possessed by the atoms or molecules that constitute that material. The internal energy embraces all the E_k, E_p., chemical energy, electrical energy, nuclear energy and all other forms possessed by the particles of that substance. Additionally, the translation, rotational and vibrational motion of gas particles can be carried over to liquids and solids to give more clarity to this complex relationship of energy forms.

Heat refers to the transfer of energy from one object to another because of a difference in temperature. Some amount of thermal energy is absorbed, lost or transferred from one object to another. The direction of heat flow between the objects depends on their temperatures, not on the amount of internal energy each has. (Example: if we mix 50g of water at 30°C water with 200 g of water at 25°C energy flows from the 30°C water to the 25°C water. This occurs even though the internal energy of the 200 g of 25°C is greater.) The symbol for heat energy is ΔQ (change in energy) and this flow stops when the mixture reaches an equilibrium temperature.

Temperature is a measure of the kinetic energy of the individual particles. Temperature is a physical property that determines the direction in which the heat energy will flow between the substances. As temperature changes the energy present in a system will increase or decrease in direction proportion to the change in temperature. Example of a pan of cold water placed on a hot stove burner. Situation places two objects at different temperatures in contact. Heat will spontaneously flow from hot to cold. If there is enough time the temperatures will equalize and thermal equilibrium is reached with no further heat flow between the objects. There is a transfer of heat due to the difference in temperature.

Hopefully, this discussion has given you some historical and practical perspective on heat exchange. This investigations that follow will use these principles to quantify the amount of heat energy that is involved in a variety of interactions.

There is a lot of bookkeeping that needs to be addressed to keep track of all the places where heat energy could be lost or gained. My hope is that these exercises will be challenging and exciting for the teacher as well as the students. Most of these investigations will produce good results with a small amount of error.

Conduction

When one end of a metal rod was placed in a flame the entire rod became hot enough to burn the student's hand. The flame's energy must have traveled through the rod to reach the hand. The majority of the metals students used in the laboratory allowed heat to flow and are termed heat conductors. Students analyzed Al, Cu, Fe and brass (alloy of Cu and Zn). To explain this phenomenon scientists first used kinetic molecular theory. Generally when one end is heated, the atoms (molecules) vibrate faster, strike nearby molecules and this process cascades down the rod. This process, in theory, allows heat to travel through the rod. In poor conductors the atoms or molecules are further apart and the increased motion will not be transferred as easily. (There is no rapid heat conduction.) Conduction seems to be a point-by-point process of heat transfer. In the early 1800s J.B. Fournier first described the transfer of heat through a solid. He felt conduction was dependent on geometry, thermal conductivity and the temperature gradient through the metal. The following formula allows the calculation of heat conduction:

$Formula \frac{Q}{t} = \frac{kA\Delta T}{L}$ Q = Heat in J

t = time (1 sec)

k = thermal conductivity (J/(sec · m · °C)

A = cross section area (m^2)

L = length (m)

A second theory of conduction addresses the chemical bond strength of the material. The atomic nucleus and its electrons in a solid are said to be bound to their equilibrium positions. However, when the metal is heated some electrons are excited to higher energy levels, which are connected by molecular orbitals within the metal (this is generally referred to as a sea of electrons). Electrons get excited into these higher-level conduction bands and can travel throughout the metal. Electrons can pick up E_k in collision with hot cores and lose E_k in collision with cooler cores. The average path for these free electrons is larger than the vibrational distance between atoms and allows the thermal energy to move through the metal. Now we have two ideas for conduction: energy transfer by molecular collision and energy transfer by the collision of free electron within the metal.

Conduction Homework

Name______________________________Date__________ Hour______

1. On either side of a pane of window glass, temperatures are 21°C and -18°C. How fast is heat conducted through such a pane of area 2500 cm^2 if the thickness is 2 mm and the thermal conductivity = .628 $J \cdot s^{-1} \cdot m^{-1} \cdot C\ deg^{-1}$?

2. Sheets of brass and steel, each of thickness 1 cm, are placed in contact. The outer surface of the brass is kept at 100°C and the outer surface of the steel is kept at 0°C. What is the temperature of the common interface? The thermal conductivities of brass and steel are in the ratio of 2:1.

3. A steel rod of length L=20 cm and cross-sectional area $A=3cm^2$ is heated at one end to T_1 = 300˚k while the other end rests in ice. Assuming that heat transmission occurs exclusively through the rod (without losses from the walls), calculate the mass m of the ice melting in time Δt = 10 min. The thermal conductivity of steel is k = 66.9 $J \cdot deg^{-1} \cdot sec^{-1} \cdot m^{-1}$.

4. Determine the power required to maintain a temperature difference of 20°C between the faces of a glass window of area 2 m^2 and thickness 3 mm. Why does a much lower power suffice to keep a room with such a window at a temperature 20°C above the outside? The thermal conductivity of glass is 1.045 $J \cdot s^{-1} \cdot m^{-1} \cdot C\ deg^{-1}$.

Conduction Homework

5. The passenger compartment of a jet transport is essentially a cylindrical tube of diameter 3 m and length 20 m. It is lined with 3 cm of insulating material of thermal conductivity .0419 $J \cdot m^{-1} \cdot C\ deg^{-1} \cdot s^{-1}$, and must be maintained at 20°C for passenger comfort, although the average outside temperature is -30°C at its operating height. What rate of heating is required in the compartment neglecting the end effects?

6. A major source of heat loss from a house is through the windows. Calculate the rate of heat flow through a glass window 2.0 m x 1.5 m in area and 3.2 mm thick, if the temperatures at the inner and outer surface are 15.0°C and 14.0°C, respectively. Thermal conductivity = .84 $J \cdot m^{-1} \cdot C\ deg^{-1} \cdot s^{-1}$

7. Calculate the rate of heat flow by conduction in Example 10 assuming there are strong gusty winds and that the external temperature is – 5°C.

8. Over what distance must there be heat flow by conduction from the blood capillaries beneath the skin to the surface if the temperature difference is 0.50 C°? Assume 200 W must be transferred through the whole body's surface area of 1.5 m^2. Thermal conductivity = .2 $J \cdot m^{-1} \cdot C\ deg^{-1} \cdot s^{-1}$

Conduction Homework

9. The rectangular-shaped building 4 m wide x 5 m deep x 3 m tall has concrete walls and a concrete roof 25.0 cm thick. If the outside temperature is 0.0˚C and the inside temperature is 20.0˚C, what is the hourly heat loss by conduction, assuming a negligible heat loss through the floor? For simplicity disregard the difference of heat conduction through walls and windows.

10. A room has a single window of crown glass 0.5 cm thick with the dimensions of 0.500 m wide and 1.00 m tall. If the outside temperature (T_c) is –3.0˚C (270K) and the inside temperature (T_h) is 27.0˚C (300K), calculate the heat loss from conduction through the window and radiation by the window.

11. The glass in a storm window is crown glass 0.5 cm thick. The outside temperature is –10.0˚C and the inside temperature is 0.0˚C. If 1.0 g of moisture condenses on 0.33 m^2 of the inside surface of the glass, determine the time for the water to freeze.

12. A steam pipe is covered with 1.50 cm thick insulating material with a thermal conductivity of 83.7 $J \cdot m^{-1} \cdot C\ deg^{-1} \cdot s^{-1}$. How much energy is lost every second by heat when the steam is at 200˚C and the surrounding air is at 20.0˚C? The pipe has a circumference of 20.0 cm and a length of 50.0 m. Neglect losses through the ends of the pipe.

Conduction Homework

13. A box with a total surface area of 1.20 m^2 and a wall thickness of 4.00 cm is made of an insulating material. A 10.0-W electric heater inside the box maintains the inside temperature at 15.0°C above the outside temperature. Find the thermal conductivity k of the insulating material.

14. A glass window pane has an area of 3.00 m^2 and a thickness of 0.600 cm. If the temperature difference between its surfaces is 25.0°C what is the rate of energy transfer by conduction through the window?

15. A bar of gold is in thermal contact with a bar of silver of the same length and area. One end of the compound bar is maintained at 80.0°C, while the opposite end is at 30.0°C. When the rate of energy transfer by conduction reaches steady state, what is the temperature at the junction?

Radiation Homework

Physics for Scientists and Engineers (Serway, Beichner)

1. A student is trying to decide what to wear. The surroundings (his bedroom) are at 20.0 °C. If the skin temperature of the unclothed student is 35°C, what is the net energy loss from his body in 10.0 min by radiation? Assume that the emissivity of skin is 0.900 and that the surface area of the student is 1.50 m^2. (Ex. 629)

2. The surface of the Sun has a temperature of about 5800 K. The radius of the Sun is 6.96 x 10^8 m. Calculate the total energy radiated by the Sun each second. (Assume that e = 0.965). (Ex. 636-48)

3. The tungsten filament of a certain 100-W light bulb radiates 2.00 W of light (The other 98 W is carried away by convection and conduction.) The filament has a surface area of 0.250 mm^2 and an emissivity of 0.950. Find the filament's temperature. (The melting point of tungsten is 3 683 K.) (Ex 636-50)

4. At high noon, the Sun delivers 1000 W to each square meter (m^2) of a blacktop road. If the hot asphalt loses energy only by radiation, what is its equilibrium temperature? (Ex 636-51)

Radiation Homework

Physics – McCliment

5. A room has a single window of crown glass 0.5 cm thick with dimensions of 0.500 m wide and 1.00 m tall. If the outside temperature (T_c) is –3.0°C (270K) and the inside temperature (T_h) is 27.0°C (300 K), compare the heat losses from conduction through the window and radiation by the window. Assume the emissivity of the room is 0.9. (Ex 369-12-9)

6. The sun is 1.5×10^{11} m from earth. It has a diameter of 8.7×10^{8} m and a surface temperature of 1.0×10^{4} K. Treating the sun as a blackbody, determine the energy radiated per second from the surface of the sun. Assume the temperature of the surrounding universe is 2.7 K (Ex 382-19)

Physics - Giancoli

7. An athlete is sitting unclothed in a locker room whose dark walls are at a temperature of 15°C. Estimate the rate of heat loss by radiation assuming a skin temperature of 34 °C and e = 0.70. Take the surface area of the body not in contact with the chair to be 1.5 m^2. (Ex 416- 14-10)

8. What is the rate of energy absorption from the sun by a person lying flat on the beach on a clear day if the sun makes a 30° angle with the vertical? Assume that e=0.70, the area of the body exposed to the sun is 0.80 m^2 and that 1000 W/m^2 reaches the earth's surface. (Ex 418-14-11)

Radiation Homework

9. (a) How much power is radiated by a tungsten sphere (emissivity e=0.35) of radius 18 cm at a temperature of 25°C? (b) If the sphere is enclosed in a room whose walls are kept at –5°C what is the *net flow rate* of energy out of the sphere? (Ex 421-31)

10. The cool red giant star Betelgeuse has a radius $r = 3.1 \times 10^{11}$ m. (If it were centered on our sun, it would extend out beyond Mars.) Its surface temperature is 2800 K (about half that of our sun). Assuming it is a perfect emitter (e=1.0) what is its power output? (Ex 421-33)

11. At approximately what rate does the top of a person's head absorb the sun's energy on a clear day, if: (a) it is covered with hair (e=0.75), has a surface area of 225 square centimeters (assumed flat), and the person stands straight with the sun making an angle of 40° with the vertical; or if (b) it is bald with e=0.20 under the same conditions. (Ex421-34)

12. The earth receives about 430 W/m^2 from the sun averaged over the whole surface and radiates an equal amount back into space (that is, the earth is in equilibrium). Assuming the earth is a perfect emitter (e=1.0), estimate its average surface temperature. (Ex 422-36)

Radiation Homework

13. (a) Find the total power radiated into space by the sun assuming it to be a perfect emitter at T=5500 K. The sun's radius is 7.0×10^8 m. (b) From this; determine the power per unit area arriving at the earth. 1.5×10^{11} m away. (Ex 423-?)

College Physics – Serway & Faughn

14. A student trying to decide what to wear is staying in a room that is at 20°C, If the skin temperature of the unclothed student is 37°C, how much heat is lost from his body in 10 min. assuming that the emissivity of skin is 0.9. Assume that the surface area of the student is 1.5 m^2. (Ex 273)

15. Two identical objects are in the same surroundings at 0°C. One is at a temperature of 1200 K and the other is at 1100 K. Find the ratio of the power emitted by the hotter object to the power emitted by the cooler object. (Ex 281-25).

16. A thin tungsten filament has dimensions of 2.5 cm by 0.25 cm. When the temperature of the filament is 3000 K and that of its surroundings is 0°C the filament emits energy at the rate of 65W. Calculate the emissivity of the filament at its operating temperature (Ex 281-26)

Radiation Homework

17. A sphere that is to be considered a perfect blackbody radiator has a radius of 0.06 m and is about 200°C in a room where the temperature is 22°C. Calculate the rate at which the sphere radiates energy. (Ex 281-27)

18. The filament temperature of a lamp increases as the power delivered to the filament increases. If the filament temperature is 2500 K when the power level is 60W, what power is required to increase the temperature to 4000 K? (Ex 281-32).

Modern Technical Physics - Beiser

19. A small hole in a cavity behaves like a blackbody because any radiation that falls on it is trapped inside by multiple reflections until it is absorbed. At what rate does radiation escape from a hole 10 cm^2 in area in the wall of a furnace whose interior is at a temperature of 700°C? (Ex 407-3)

20. A copper sphere 5 cm in diameter whose emissivity is 0.3 is heated in a furnace to 400°C. At what rate does it radiate energy? (Ex 407-4)

Radiation Homework

21. An object is at a temperature of 400°C. At what temperature would it radiate energy twice as fast? (Ex 407-5)

22. A certain 50-kg woman has a surface area of 1.5 m^2 and a skin temperature of 34°C. When she is sitting still in a room at 20°C her metabolic activity leads to the liberation of 80 W. To see whether it is plausible that radiation is the chief mechanism by which this power is dissipated, calculate what her effective emissivity must be for her to lose energy at 80 W under the above conditions. (Ex 407-6)

CALORIMETRY HOMEWORK PROBLEMS

1. A calorimeter contains 400 g of water at 20.0°C. How many grams of steam at 100.0°C are needed to raise the temperature of the water and calorimeter to 80.0°C? The calorimeter has a mass of 100. g; its specific heat is 0.100 cal/gC°.

2. In an experiment to determine the heat of vaporization of water, 15.0 g of steam at 100.0°C is added to 150.0 g of water at 20.0° in a calorimeter. The mass of the calorimeter is 75.0 g; its specific heat is 0.100 cal/g C°. The equilibrium temperature of the mixture is 73.9°C. What is the heat of vaporization of water?

3. A mixture of ice and water, mass 200.0 g, is in a 100.0-g calorimeter, specific heat 0.200 cal/g C°. When 40.0 g of steam is added to the mixture, the temperature is raised to 60.0°C. How many grams of ice were originally in the calorimeter?

4. An aluminum cylinder, mass 50.0 g, is placed in a 100.0-g brass calorimeter with 250.0 g of water at 20.0°C. What equilibrium temperature is reached after the addition of 25.0 g of steam at 120.0°C?

5. To what temperature must a 500-g brass weight be heated to convert 60.0 g of ice at –20.0°C to water at 20.0°C?

6. What is the final temperature of a mixture of 50.0 g of ice at 0.0°C and 50.0 g of water at 80.0°C?

7. What is the final temperature when 300? g of ice at 0.0°C, 500. g of ice water at 0.0°C and 1200.g of water at 100.0° are mixed?

8. A calorimeter, specific heat 0.100 cal/gC°, mass 200.0 g, contains 300.0 g of water at 40.0°C. If 50.0 g of ice at 0.0°C is dropped into the water and stirred, the temperature of the mixture when all the ice has melted is 23.8°C. Calculate the heat of fusion of ice.

9. A block of silver, mass 500.0 g, temperature 100.0°C, is put in a calorimeter with 300.0 g of water, temperature 30.0°C. The mass of the calorimeter is 50.0 g and its specific heat is 0.100 cal/gC°. A block of ice, mass 50.0 g, temperature – 10.0°C, is then also put in the calorimeter. Calculate the final temperature.

10. State the law of heat exchange in simplest terms.

11. Define specific heat capacity.

12. What is the meaning of the expression: ΔQ?

13. Ten grams of a substance with a specific heat capacity of 0.50 cal/g•C° are heated 2.0 C°. What quantity of heat is absorbed?

14. How many calories are required to warm 100 g of copper from 10.0°C to 50.0°C?

15. A 120-g mass of a metal is heated to 100°C and dropped into a glass calorimeter of mass 100 g containing 300 g of water at 15°C. The final temperature is 25°C. What is the specific heat of the substance?

16. A student tries to identify a metal by measuring its specific heat capacity. The metal, weighing 63 g, is heated to 99.5°C and then transferred to a copper calorimeter of mass 72 g containing 178 g of water at 20.5°C. The final temperature of the mixture of 26.0°C. Find the specific heat capacity of the metal.

17. How much frictional work is required to raise the temperature of 10.0 kg of water from 30.0° to 55.0°C?

18. A 1000-watt percolator holds 3.0 kg of water at 20°C. To what temperature would it heat the water in 5.0 min if all the electrical energy were used to heat the water?

19. An electric motor has an input of 200W and an output of 180 W. (a) How much heat will it produce in 10 min if all of the wasted energy is converted to heat? (b) How many grams of water could be heated from 20°C to 100°C by this heat?

20. A mass of 250 g of lead shot at 100.0°C is poured into 150 g of water at 10.0°C in a 100-g cup of a material with a specific heat capacity of 0.10 cal/g•C°. The final temperature is 14.0°C. Find the specific heat capacity of the lead.

21. A 160-g mass of copper at 96.0°C is placed in 180 g of water at 22.0°C in an aluminum calorimeter of mass 70 g. What is the final temperature?

22. Enough heat is supplied to 100 g of ice at 0°C to melt it. If the same quantity of heat is supplied to 100 g of water at 0°C, how hot does the water become?

23. What is the symbol for heat of fusion?

24. How many calories must be absorbed to melt 80 g of lead?

25. How many calories will be given up if 200 g of water cools from 100°C to the freezing point and then freezes?

26. How much frictional work is required to melt 1.0 g of ice?

27. How much ice at 0°C must be added to 2000 g of water at 25°C, in order that the final temperature may be 0°C? Assume that no heat is exchanged with the container or surroundings.

28. A 200-g mass of hot copper is dropped on a block of ice at 0°C. As a result, 210 g of ice are melted. How hot was the copper at the beginning?

29. How much heat is required to evaporate 20.0 g of water?

30. How much heat is required to warm 30.0 g of water from room temperature (20.0°C) to the boiling point and then to evaporate all of it?

31. How much heat is given up by the condensation, cooling, and freezing of 100 g of steam? Assume the initial and final temperatures to be 100°C and 0°C.

32. A 20-g mass of steam is condensed in 2500 g of water at 10°C. What is the final temperature of the mixture? Assume no heat lost to the outside.

33. Normal body temperature is 37°C. Compare the number of calories of heat you rece3ive from a burn due to the cooling of 10 g of boiling water from 100°C to body temperature, with the number of calories of heat you receive from a burn due to the cooling of 10 g of steam from 100°C to body temperature.

34. If some ice at 0°C is melted, warmed, and boiled away at 10°C to form steam at 100°C, what percent of the energy supplied has become potential energy? What has become of the rest of the energy supplied?

35. How much ice must be used to cool 200 g of water at 20°C to 0°C, if all the ice is melted in the process?

36. If 25 g of ice at 0°C are added to 200 g of water at 20°C, what is the final temperature after all the ice is melted?

37. A 100-g mass of melted lead at its melted point (327°C) is poured into 200 g of water at 22.5°C in a 50-g copper calorimeter. The final temperature of the mixture is 30.0°C. Find the heat of fusion of the lead.

38. How many grams of steam are required to melted 40 g of ice at 0°C and produce a final temperature of the mixture of 50°C?

39. A copper calorimeter weighs 80 g. Water at 5°C is poured in until the calorimeter and contents weigh 280 g. Steam at 100°C is run through the water until the temperature is 35°C. When the calorimeter and contents are weighed at the end, the weight is 290 g. Find the heat of vaporization of the water and compute the percent of error.

40. How many calories of heat are needed to change 30 g of ice at –5° C to water at 20°C?

41. How much ice at 0°C is needed to cool 250 g of water at 25°C to a temperature of 0°C?

42. An 18-g ice cube (at 0°C) is dropped into a glass containing 150 g of Coke at 25°C. If negligible heat exchange occurs with the glass, what will be the final temperature of the Coke after the ice melts?

43. Molten lead at 327°C is poured into a cavity of a block of ice at 0°C. How much ice will be melted by 40 g of lead? Assume temperature equilibrium with the block is achieved.

44. If 100 g of lead shot at 100°C is dropped into 50 g of water at 20°C contained in a copper calorimeter can of 50 g mass, what is the resulting temperature?

45. To 100 g of water contained in a 50-g copper calorimeter at 35°C is added 20 g of ice at –10°C. What is the final temperature?

46. How much steam at 100°C is needed to change 40 g of ice at –10°C to water at 30°C if the ice is in a 50-g copper calorimeter?

47. A 70-g calorimeter can [c = 0.20 cal/(g)(°C)] contains 400 g of water and 100 g of ice at equilibrium. To this is added a 300-g piece of metal [c = 0.10 cal/(g)(°C)], which has been heated to a high temperature. The final temperature is 10°C. What was the original temperature of the metal?

48. 200 grams of gold at 100°C is placed in a calorimeter containing 300 grams of water at 20°C. The final temperature of the mixture is 21.6°C. What is the specific heat of gold?

49. 27.6 grams of steam is added to a calorimeter containing 400 grams of water at 20°C. The final temperature is 60°C. What is the heat of vaporization of water?

50. A metal block of mass 500 g is warmed from 20°C to 30°C when it absorbs 1200 calories of heat energy. Calculate the specific heat of the metal.

APPENDIX C

Activity 1 – Thermometers – Feeling Temperature – Student Edition

Topic – Physically Sensing Temperature

Title – Thermometers – Feeling Temperature

Procedure:

1. Is your physical sense of temperature reliable?
2. Prepare containers of hot water, warm water and cold water.
3. Put both hands in warm water – the hands will feel the same temperature.
4. Now put one hand in hot water and the other in cold water. Then quickly dry your hands and put them into the warm water.

Conclusion:

Activity 2 – Estimation of Temperature - Student Edition

Topic – Temperature

Title – Estimation of Temperature

Background:

From your experience with hot, cold and warm water students can find it difficult to judge exactly how hot or cold an object is by simple touch. A much more accurate way for determination of temperature involves the use of a thermometer (usually in °C). This investigation will give the student some indication, by discovery, how much they know about temperature (human body 37°C).

Procedure:

1. Students should copy a. through n. to note cards:

a. Boiling water	h. Room temperature
b. Hot tea	i. Healthy human being
c. Coldest possible temperature	j. Ice cream cone
d. Surface of sun	k. Freezing water
e. Interior of sun	l. Comfortable bath water
f. Hottest day on earth's surface	m. Coldest weather recorded on earth's surface
g. Air in a refrigerator	n. Oven when pizza cooks

2. In your group, discuss each card and estimate its temperature. Sort into low, every day, and high temperature.
3. Students should now discuss each pile separately and arrange the cards in that pile from coldest to hottest.
4. Now refer to the temperature cards that are provided. Match these temperature cards with the first set and see if you can match them up.
5. In your notes record the temperature that was agreed on for items 1-14. List them from coldest to hottest.

Activity 2 – Estimation of Temperature - Student Edition

Questions:

1. Check your values against the actual temperature. (How good was your group at prediction?)
   a. Which temperatures were easy to predict?
   b. Which temperatures were hard to predict?
2. Which cards are easier to rank from hot to cold 1-14 (item cards) or A-N (temperature cards) Why?
3. How does knowing the objects temperature help in scientific observations
4. What do you remember about temperature scales? Fahrenheit (°F), Celsius (°C), Kelvin (K),

Conclusion:

Where did you individually have the most problem?

1 Boiling water		2 Hot tea
3 Coldest possible temperature		4 Surface of sun
5 Interior of sun		6 Hottest day on earth's surface
7 Air of refrigerator		8 Room temperature

9 Healthy human being		10 Ice cream cone
11 Freezing water		12 Comfortable bath water
13 Coldest weather recorded on earth's surface		14 Oven when pizza cooks

A -273 degrees C		B -89 degrees C
C 80 degrees C		D -10 degrees C
E 100 degrees C		F 20 degrees C
G 58 degrees C		H 15,000,000 degrees C
I 37 degrees C		J 160 degrees C
K 0 degrees C		L 40 degrees C
M 6000 degrees C		N 7 degrees C

Activity 3 – Historical Dialogue – Temperature and Heat - Student Edition

Topic – Historical Dialogue

Title – Historical Dialogue – Temperature and Heat

Background:
Most students would predict that if heat energy is added to a substance its temperature would rise.

1. What does this mean?
2. What is heat?
3. Put your hand in cold water. Why does your hand feel cold? (Heat transfers from the hand to the surrounding water. Your hand detects this loss and tells you the environment is cold.)
4. Heat flows from your hand to cold water.
5. Heat flows from the sun to your skin.
6. Heat flows from the stove to the pot.
7. Heat flows from the tongue to the ice cream.
8. Heat is transferred but what is it?

Historical Dialogue:
Problem of heat transfer puzzled the world's natural philosophies and the story of Antoine Lavoisier's hypothesis points this out.

Great Moments in the History of Heat – Lavoisier is famous today for his work in Chemistry but he also studied Physics. His wife, Marie Anne, often helped him with his studies. Marie would translate papers from English to French to help him.

Ant.- "Marie Anne could you please bring me another candle, mine is nearly out.

Marie reaches for the candle and is suddenly burned.

Marie – "Ouch!!"

Ant.- "What happened my dear?

Marie – "Nothing really. However, I burned my hand slightly as I changed the candle."

Ant. – "Now that is interesting as I was just working on a theory about how heat moves."

Marie – "May I see? Oh so your hypothesis is that heat is a substance that has mass."

Ant. – "Yes Marie. Let me draw you a diagram to help explain. I will use what happened to you as an example. Which was hotter, Marie, the candle wax or your hand?

Marie – "Well obviously my burned finger proves that the wax was hotter."

Ant. - "My hypothesis states that when an object, your finger my dear, touches a warmer object, the candle in our case, the caloric fluid flows from the warmer object to the cooler object. My best guess states it was the heat fluid caloric that burned your hand."

Marie – "Antonine your hypothesis sounds very logical however my question concerns the mass of this caloric fluid."

Ant. – "Marie, it is late but I will design an experiment to test this hypothesis. We will discuss this more at a later date after my investigations."

Questions:

1. What were Lavoisier's fields of interest?

2. Why do you think the wax dropping on Marie's hand was important as Lavoisier studied heat and temperature?

3. How does the dropping wax relate to Lavoisier's theory of how heat moves?

4. What did Lavoisier mean by "caloric"?

5. What important questions did Marie Anne ask her husband about his theory?

6. In your own words, state Lavoisier' hypothesis.

7. Do you see any problems with this hypothesis?

8. According to his hypothesis, what should happen as an object is heated? Cooled?

9. What type of investigation would you do to test Lavoisier's hypothesis?
   a. Submit your design.
   b. Carry out the experiment.
   c. Do the results support the hypothesis?

Conclusion:

What do you conclude about Lavoisier's caloric fluid?

Activity 4 – Testing a Thermometer - Student Edition

Activity – Demonstration

Topic – Thermometer Accuracy

Title – Testing a Thermometer

Procedure:

1. Check available thermometers in ice water and boiling water (Check boiling point and freezing point)
2. May want to buy blank thermometers and have kids invent their own scales and come up with a way to mark off the scale.

Conclusion:

Activity 5 – Probe a Flame with a Small Thermocouple and Ampmeter - Student Edition

Topic – Thermocouple

Title – Probe a flame with a small thermocouple and ampmeter.

Procedure:

The temperature of the flame parts will vary.

Observations:

Conclusion:

Activity 6 – Transfer of E_k to Heat Energy - Student Edition

Topic – Conduction (by friction)

Title – Transfer of E_k to Heat Energy

Procedure:

1. Need a piece of thin iron wire – coat hanger?
2. Wrap a small piece of heat sheet around one end of the iron wire.
3. Hold on to the other end of the wire.
4. While holding on to the wire, hit the lead piece several times with a hammer.
5. You should be able to feel the temperature rise as heat is conducted from the lead through the wire to your hand.
6. Also feel the lead before and after it was hit by the hammer.

Data and Calculations:

Conclusions:

Activity 7 – Process of Conduction - Student Edition

Topic – Process of Conduction

Title – Process of Conduction

Procedure:

Need to use Plexiglas models on the overhead to illustrate the tenets of the kinetic molecular theory.

Also use 3 tubes with varying amounts of lead shot BBs to demonstrate solids, liquids and gases. A glass tube is packed tightly with lead shot to illustrate a solid. A vibrational wave generator is used to set up vibrations in the lead BBs to provide an analogy for the process of conduction.

Observations:

Conclusion:

Activity 8– Water is a Poor Conductor of Heat - Student Edition

Topic – Heat Conduction of Water

Title – Water is a Poor Conductor of Heat

Procedure:

1. Use your bare fingers to hold the bottom of a test tube filled with cold water.
   Tilt the test tube so you can heat the water in the upper part of the test tube.

Observations:

2. Boil water in a paper cup. Pour water into a paper cup and hold it over a flame.

Observations:

3. Put small pieces of ice in the bottom of a test tube that contains water. Need to put weights on the ice to keep ice in the bottom. Heat the water near the top with an alcohol burner.

Observations:

Conclusion:

Activity 9 – Atoms of Substance - Student Edition

Activity – Demonstration

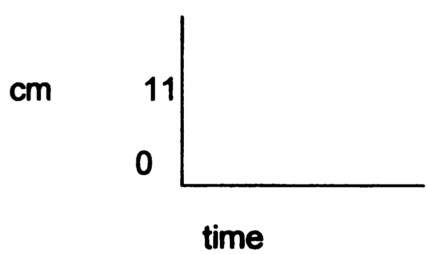
This is another activity where students can relate what they observe to kinetic molecular theory. Hopefully, they can explain what is happening to the atoms of the substance based on their observation of the bar

Topic – Kinetic Molecular Theory

Title – Atoms of Substance

Procedure:

1. Students will need 40 cm lengths of 10 gauge copper and steel wire (bar) – Steel from coat hanger with paint sanded off.
2. Need to dip wire in melted wax so 30-40 cm is coated with wax. Make certain both wires are coated the same.
3. Use a pencil point to make a mark at each 1cm mark along the waxed part of the wire. (Start at the uncut end.)
4. Support the wires horizontally and heat the unwaxed end with candles of the same diameter, height and wick length. Start a stopwatch and record the time each cm mark in the wax melts so it can't be seen (1st mark at 11 cm).
5. Students need to graph the data to allow them to visualize the time it takes heat to be conducted along each wire. The heat will melt the wax as it travels down the wire.
6. 2nd variation – also using wax
   a. Place drops of wax from a lit candle on a bar or wire at some regular interval (0-5-10-15-20-25-30).
   b. Place tacks in the hot wax before it cools (at the specific marks).
   c. As heat travels along the bar the wax melts and students can time the fall of the tacks.
   d. Use the data to construct a graph of distance vs. time.



Data and Calculations:

1st Variation		2nd Variation	
cm	time	cm	time
11		0	
12		5	
13		10	
14		15	
15		20	
16		25	
17		30	
18			
19			
20			
21			
22			
23			
24			
25			
26			
27			
28			
29			
30			

Conclusion:

Activity 10 – Conduction of Heat by Metals (Davy Miner's Lab) - Student Edition

Topic – Conduction

Title – Conduction of Heat by Metals (Davy Miner's Lab)

Procedure:

1. Hold a length of wire coat hanger horizontally over a flame with your fingers a small distance from the flame.
   a. Wire becomes too hot to hold.
   b. Progressively move your fingers back.
   c. Should feel the heat moving along the wire.

Observations:

2. Use identical lengths of different metal bars or tubes (Fe, Cu, Al, brass)
   a. Put blobs of melted wax at intervals along the bars.
   b. Put tacks or thumbtacks into the soft wax.
   c. Heat the end of the bar and the blobs will melt allowing the tacks to fall as heat moves down the bar.
      i. Time the falls.
      ii. Graph the data

Observations:

3. Hold a screen or some metal gauze (Fe 1mm) over a flame of a small candle.
   a. Lower the wire gauze and the flame gets smaller.
   b. The flame will not go through the wire netting.

Observations:

4. Humphrey Davy – Invents a miner's safety lamp
   a. Metal gauze around the flame in the lamp conducts heat away from the flame so it cannot ignite explosive gas in the coalmine.
   b. Need an unlit burner under a tripod stand and cover it with 1 mm Fe gauze.
   c. Put a metal coin or key on the paper and hold over the candle flame.

Observations:

Data and Graph:

Tack	Time	Tack	Time	Tack	Time
1		6		11	
2		7		12	
3		8		13	
4		9		14	
5		10		15	

Conclusion:

Activity 11 – Copper Coil Snuffer - Student Edition

Topic – The Effect of Heat Conduction

Title – Copper Coil Snuffer

Procedure:

1. Place a coil of heavy Cu or Al wire over the flame of a small size candle. (Flame will go out.) Why?
2. We can snuff out a candle flame if there is no O_2 but here O_2 can easily get to the flame.

Observations:

Conclusion:

Activity 12 – Conduction – Reduce Heat Loss with Insulation Materials - Student Edition

Topic – Value of Insulation

Title – Conduction – Reduce Heat Loss with Insulation Materials.

Procedure:

1. Need 4 large tin cans of equal size and 4 smaller tin cans of equal size.
2. Inside first large can put the small can sitting on 2 corks in the large can (this is the control).
3. Select types of insulating material.
   a. Sawdust
   b. Newspaper
   c. Cork pieces
   d. Plastic (foam)
   e. Fiberglass
4. Put the small cans into the larger cans and pack one type of insulation material under and around each of the small cans.
5. Cardboard cover on each large can with a hole for a thermometer.
6. Fill each small can with water that is nearly boiling (Record T_i).
7. Record the temperature of each can at regular intervals and plot a cooling curve by plotting temperature vs. time for each can.
8. What material is the best insulator?

Data and Calculations:

Time (Min)	Rise (cm)	Time (Min)	Rise (cm)	Time (Min)	Rise (cm)	Time (Min)	Rise (cm)
0		5		10		15	
1		6		11		16	
2		7		12		17	
3		8		13		18	
4		9		14		19	

Conclusion:

Activity 13 – Convection Currents (Black Pepper/Charcoal) - Student Edition

Topic – Convection

Title – Convection Currents (black pepper/charcoal)

Purpose:

Students will examine particles trapped in convection currents to see if they are moving in any particular direction.

Procedure:

1. Use a candle or small burner to heat a beaker of water. Heat source should be in the center of the beaker.
2. Use a screen between the beaker and the flame to diffuse the flame. (May want to look at this carefully.)
3. Add either:
   a. Flakes of black pepper
   b. Pinch of powdered charcoal
   c. Observe what happens to the particles and draw a diagram.
4. Move the heat source to the edge of the beaker and observe the effect on the convection currents.
5. Possible to repeat the experiment with canola oil vs. water. (Repeat the observations and do not take either above 50°C.)

Observations and Diagrams:

Conclusion:

Activity 14 – Convection in Hot Water and Cold Water - Student Edition

Topic – Kinetic Molecular Theory

Title – Convection in Hot Water and Cold Water

Purpose:

Use the demonstration as an illustration of the tenets of the kinetic molecular theory.

Procedure:

1. Students need 2 clear jars, one full of hot water (50°C+) and 1 full of ice water.
2. Add 1 drop of food coloring to each jar. Make observations and draw a diagram of what you see and include a summary of the speed of the process in both jars.
3. Use the assumptions of kinetic molecular theory to explain what is happening in each jar.

Observations:

Conclusion:

Activity 15 – Convection Current from an Ink Bottle - Student Edition

Topic – Convection in Liquids

Title – Convection Current from an Ink Bottle

Procedure:

1. Need a small ink bottle filled with a two hole stopper.
2. Need 2 pieces of glass tubing.
   a. One piece should extend from the stopper to almost the bottom of the bottle.
   b. The other piece should extend 5 cm up from the stopper.
   c. Fill the bottle with hot colored water.
3. Fill a large beaker with cold water.
4. Put the small bottle in the bottom of the large beaker and hold fingers over the ends of the tubing.

Observations:

Conclusion:

Activity 16 – Convection Currents in a Beaker - Student Edition

Topic – Convection in Liquids

Title – Convection Currents in a Beaker

Procedure:

1. Find the mass of an empty beaker (100ml).
   a. Add 80 ml of cold water.
   b. Find the mass of the cold water.
2. Repeat the process with an equal volume of 90°C water.
3. Make up a data chart and explain results.

Observations:

Conclusion:

Activity 17 – Convection Currents in a Test Tube - Student Edition

Topic – Convection (in liquids)

Title – Convection – Convection Currents in a Test Tube

Procedure:

1. Fill a test tube with cold water
2. When the water is still, add a small crystal of $KMnO_{4\,(aq)}$ and let it fall to the bottom leaving a color trace.
3. Hold the test tube with your bare fingers near the top but not above the water level.
4. Heat with a small burner or candle flame at the bottom of the tube.
   a. We can hold the tube with our bare fingers (previous experiment).
   b. Observe the movement of the dissolved K^+,MnO_4^- in the convection current. (Diagram of observation).
5. Repeat but now heat gently near the top while holding the test tube near the bottom. Explain.

Observations and diagrams:

Conclusion:

Activity 18 – Convection Currents in Air - Student Edition

Topic – Convection in Gases

Title – Convection Currents in Air

Procedure:

1. Need a disk of thin metal from a metal can.
   a. Cut 4 blades around the disk and pivot on a needle.
   b. Hold disk above a candle flame.
2. Can also use the difference in refractive indexes of warm and cold air to show air currents.
   a. Strong light will cast shadows from a convection current generated by an electric heater.
   b. Make a convection box – cut away 1 side and replace it with glass.
      i. Cut two, 2cm holes and 10 apart in the top of the box.
      ii. Attach two tubes above the holes to be chimneys.
      iii. Put a candle in the box under one chimney and light the candle.
      iv. Hold the smoking paper above each chimney.
      v. Write down your observations.
3. Students will trace convection currents
   a. Hang a T-shaped piece of cardboard from the rim of a large jar.
   b. Stem of T-shape should reach halfway down the jar.
   c. Use a wire loop to lower a lighted candle into one side of the jar.
   d. Use smoking paper to find the convection currents in the jar.
   e. Observations and diagrams.

Observations:

Conclusion:

Activity 19 – Transfer of Heat by Radiation - Student Edition

Topic – Radiation

Title – Transfer of Heat by Radiation

Background Information:

- Student activity will focus on the transfer of radiation to thermal energy.
  1. Light – photons or particles
  2. em waves that travel through space carry energy with them.
- When these em waves/particles hit an object
  1. They either reflect (metallic or white reflect)
  2. The are absorbed into the object (darker color)
  3. In a qualitative sense students can look at the object and see if anything is reflecting off the object.
  4. If the object is reflecting light that hits it, it should look like a mirror.
  5. If it is absorbing a particular color then the other colors are reflecting.
  6. Black absorbs all colors so there is no reflection.
  7. White is defined as all colors mixed together, therefore white reflects all colors at the same time.
- The quantitative way to measure the absorption of energy is to apply em radiation to several objects.
  1. Measure their relative temperature increases.
  2. Compare the temperatures (same time exposure).
  3. Higher temperature (same time interval) have absorbed more em radiation.

Purpose:

Purpose is to show the transfer of energy from radiation energy to thermal (heat) energy and from thermal energy to kinetic energy (motion). These are all forms of energy the amount of which is conserved throughout the system.

Procedure:

- Show the radiometer and discuss how it is made.
  1. The inside of the bulb is sealed (vacuum) so the wind cannot spin its vanes.
  2. There is a frictionless pivot that allows the vanes to turn easily.
  3. Each vane has a white and black side and is oriented in the same way (each is white on one side and black on the other).
- Students, is it possible to have the vanes spin without touching them?

Activity 19 – Transfer of Heat by Radiation - Student Edition

- Turn on the light bulb next to the radiometer. (Observation)

1. Put a piece of heavy paper between the light and the radiometer. (Observation)
2. Take the paper away. (Observation)
3. Why does the radiometer behave this way?
4. Is the light heating something?
5. Is the air inside being heated?
6. Are the vane wings being heated?
7. The light hits either side of the vanes equally so why does it spin?

Activity 19 – Transfer of Heat by Radiation - Student Edition

Discussion

Questions:

1. What is the difference between conduction heating and radiant heating?

2. Do different colored materials absorb different amounts of heat by radiation?

Conclusion:

Activity 20 – Feel Radiation - Student Edition

Topic – Radiation

Title – Feel Radiation

Procedure:

1. Close the window that is facing the sun.
   a. Can you feel the sun's radiation on your cheek?
   b. Stand near an open window to feel the same radiation from the sun on your cheek. Close the window.

2. Heater | 25 cm cheek
   | ←——→

Observations:

Put glass over the hole. Feel the radiation? 2 pieces of glass. How does the radiation compare?

Conclusion:

Activity 21 – Heat Transfer by Radiation - Student Edition

Activity – Demonstration

Topic – Radiation

Title – Transfer Heat by Radiation

Procedure:

1. Hold palm of hand very close to but not touching cheek. (Observation)

2. Hold hand under an unlighted electric bulb, palm upward.
   a. Turn on electricity. (Observation)

   b. Air is a poor conductor of heat so the heat could not reach your hand quickly by conduction.

   c. Convection would carry the heat up and away from your hand; therefore heat could not reach your hand this way.
   d. How does the heat reach your hand?

3. Put glass between the light bulb and your hand to block air movement.

Observations:

Conclusion:

Activity 22 – Different Kinds of Surfaces Affect Radiation - Student Edition

Topic – Radiation

Title – Different Kinds of Surfaces Affect Radiation

Procedure:

1. Use 3 same size metal cans.
   a. Paint one white inside and out.
   b. Paint one black inside and out.
   c. Third can remain shiny.
2. Fill the 3 metal cans to be the same level with warm water at the same temperature.
   a. Record T_i
   b. Put on cardboard covers with holes for thermometers in each can.
   c. Put the metal cans in a cool place and record the temperature of each can at 5-minute intervals.
   d. Graph the results and describe the difference in the rate of cooling. Try to explain the differences.
3. Reverse the process and fill the cans with very cold water (ice water without the ice).
   a. Record T_i for each can.
   b. Put the cans in a warm place in the sun or shine lights on the box.
   c. Record temperature at 5-minute intervals.
   d. Graph results and describe the difference in the rate of warming. Try to explain the differences.
4. Extra credit – Use a pair of old shoes. Pain the left shoe black and the right shoe white. What do you observe when you wear the shoes for the day?

Data and Graph:

Cool Place		Warm Place	
Time (Min)	Temperature (°C)	Time (Min)	Temperature (°C)
0		0	
5		5	
10		10	
15		15	
20		20	
25		25	
30		30	

Activity 23 – Focus Radiant Heat Waves - Student Edition

Topic – Radiation

Title – Focus Radiant Heat Waves

Procedure:

1. Use a magnifying glass to focus rays of the sun on a piece of tissue paper.
   (Observation)

2. Repeat with tissue paper soaked in black ink (after ink dries).
   (Observation)

3. Focus sun's rays on your arm. (What happens?)

4. Make the spot as small and bright as possible. This is called the focal length of the lens.

5. How do the two distances compare?

Observations and Diagram:

Conclusion:

Activity 24 – Reflect Radiant Heat Waves - Student Edition

Topic – Radiation

Title – Reflect Radiant Heat Waves

Procedure:

1. Heat tissue paper with a magnifying glass.
   a. Note distance from reading glass to paper.
   b. Put a tilted mirror ½ way from lens to paper.
   c. Feel with your hand above the mirror until you find the point where the heat waves are focused.
2. What would happen if white or black paper is placed at this point?

Observations and Diagram:

Conclusion:

Activity 25 – Web Research – Extra Credit - Student Edition

Topic – Research (Solar Homes)

Title – Web Research – Extra Credit

Purpose – (Web Activity):

Select websites that include designs for passive and actively heated solar homes.

Procedure:

Using the information found on the web explain the difference between the two designs and the conditions that are necessary for each to meet its design expectations. (Where would we build homes of this type and why?)

Activity 26 – Check R Values on Web – Extra Credit - Student Edition

Topic – Check Values on Web

Title – Check R Values on Web – Extra Credit

Procedure:

Students will discuss R-values (insulation values) and the cost of commercially available insulation material. Students will relate the cost to insulate an area to the desired RSI value using different material and decide which meets their needs and their budget.

1. Lumber yard
2. Web

Observations:

Conclusion:

Activity 27 – Solar Energy Trap - Student Edition

Topic – Solar Energy Trap

Title – Solar Energy Trap

Purpose:

Group needs to design, build and test a solar energy trap.

Procedure:

1. Students need to build a device that will absorb and trap solar energy heating up the inside of the device.
2. Main objective is the measure the internal temperature one hour after exposure to sunlight.
3. Other possible criteria could be:
   a. Cost of construction
   b. Rate at which heat is lost after removal from the sun.
4. Students could also measure the temperature inside parked cars on a sunny day.
   a. Monitor different locations (trunk, floor level, dashboard, rear window).
   b. Compare interior and exterior
   c. Shield thermometers so they are not directly in the sun.

Observations:

Conclusion:

TEACHING HEAT TRANSFER AND HEAT EXCHANGE

VOLUME II

By

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APPENDIX D

Lab 1 – Heat Exchange: Hot Brick Placed in Cool Water – Student Edition

Purpose:

Part I (Qualitative)

1. Make qualitative observations of a system that undergoes heat exchange. Place a hot brick in a Styrofoam cooler containing cold water.
2. Observations are qualitative (what you see, hear, feel, smell or taste).
3. If you try to explain the process you are interpreting and are not making observations.
4. Write a type 1 response that includes your observations.

Part II (Quantitative)

1. Have a class discussion that addresses quantities that could be physically measured in this investigation.
2. Decide with lab partner what measurements will be made. (Repeat the investigation and make the measurements that interest you.)
3. Can you use these measurements to make any calculations? If you can calculate something, explain your reasoning.
4. When the class discusses everyone's work, make a record of some things you may want to try yourself.
5. Do a third trial if necessary and do any additional measuring needed.
6. Use these measurements to write a second type 1 response.

Equipment:

1. Styrofoam cooler
2. Water
3. Brick
4. Oven
5. Thermometer
6. Balance
7. Graduated cylinder (larger)
8. Smaller brick sample
9. Styrofoam calorimeter (2 cups)
10. Ruler

Procedure:

1. Place warm brick in cool water (brick piece and Styrofoam cups).
2. Using only qualitative techniques (see, hear, feel, smell and taste) describe what is happening in this system.
3. Write a type 1 response that is a summary of your observations.
4. Have a class discussion that addresses what could be physically measured in this investigation (make a list).
5. Decide with your lab partner which measurements you will make. Repeat the investigation and make the measurements that interest you.
6. Use these measurements to write a type 1 summary of changes that occurred during the course of this investigation.

7. Share your work with other lab groups and see if there are some things you would like to include in your lab that you may not have accomplished.
8. Do a third trial (if needed) to make any additional measurements you think need to be accomplished.
9. Can you use these measurements to calculate anything?

Data:

Measurements	
1.	
2.	
3.	
4.	
5.	

Calculations:

Calculations	
1.	
2.	
3.	
4.	

Conclusion (Summary):

Type 1 Summary – initial experiment

Type 2 Summary – based on your measurements

Lab 1 – Heat Exchange: Hot Brick Placed in Cool Water – Student Edition

The following information was gleaned from the John J. Collins, Ed.D. Education Associates publication *Developing Writing and Thinking Skills Across the Curriculum: A Practical Program for Schools.*

Type 1 Writing:

- Students are encouraged to get their ideas on paper (brainstorming). This is the idea generating, recollecting, data gathering, exploring or questioning phase of the writing and thinking process.
    1. Completed in 7-10 minutes.
    2. Done individually (may be with no class discussion).
    3. Students get time to think about a topic (can quiet the room).
    4. Gives insight about how much each student knows about the topic.
    5. Can replace or precede classroom discussion.
    6. Can be used at the beginning of a unit (what do you know about this topic?)
- Sometimes teachers can have a few students read their papers and allow the class to organize the ideas (3 columns)
    1. Facts
    2. Questions
    3. Miscellaneous

  This activity makes students active listeners, as they need to categorize and evaluate ideas as they are read (students talk, listen and think about the topic under investigation).
- Format
    1. Only one draft.
    2. Use the sheet provided (names on right and type 1 on left)
    3. Students need to remember to skip lines.
- Grading
    1. See if the amount of writing was generated.
    2. Reading is optional (create atmosphere of no risk).
    3. Objective is to help students discover what they know.
    4. Grade is usually a √.

Type 2 Writing:

- Type 2 writing shows that the writer knows something about the topic or has thought about the topic; it is best used as a quiz. It is the correct answer to a teacher's prompt.
    1. Evaluation criteria; the content must be correct (ask for definitions, facts, explanations, or opinions supported with details).
    2. Spelling, punctuation and capitalization do not count.
        a. If writing is really poor, good ideas may be lost.
        b. Evaluate the content, not the way the content is expressed.
    3. Keys for successful type 2 writing.
        a. Prompt or question is clear and has a definite answer.
        b. Students make their own meaning by translating concepts into their own words.
        c. Vague question gets a vague answer and is hard to evaluate.
- Format for type 2
    1. Because its primary use is to quiz students, type 2 frequently takes the form of an essay, list or definition.
        a. Students should be encouraged to write what they know, or how they feel in response to a prompt.
        b. Students should be discouraged from adding lines or pages to pad answers. Good answers or ideas can be obscured in the fog of their own words.
        c. As students experience type 2 writing, they will learn the distinction between padding a response and using writing as a tool to develop and elaborate on ideas.
- Audience – The teacher has high expectations about the content of the writing but not about how skillfully or perfectly the content is expressed.
- Evaluation
    1. Best for a question that requires a limited, specific and predictable response.

2. Questions or prompts with a number in them are good for type 2.
    a. List 3 possible causes.
    b. Define 3 of the terms on overhead.
    c. Explain the two main points.
3. Keep evaluation as simple as possible.
    a. Teacher can skim paper to find correct response.
    b. Use pass/fail.
    c. Wake up call for students.
    d. Teacher choice – need to be simple, quick and require teacher to skim written work to get correct response
4. Type 2 is quiz writing and is not used for a major test.
    a. Can be part of a report card grade.
    b. Can be used for the effort grade.
5. As the frequency of type 2 increases, the number of papers that need to be evaluated decreases.
    a. . May assign 20 writings and collect only 10.
    b. Students need to be engaged, never knowing if an assignment will be collected.

Lab 1 – Heat Exchange: Hot Brick Placed in Cool Water – Student Edition

Type ________ Name ________________________________

	X	
	X	
	X	
	X	
	X	
	X	
	X	
	X	
	X	
	X	
	X	
	X	
	X	

Lab 2 – Heat Loss (Measuring the Rate of Cooling) – Student Edition

Purpose:
To measure the insulating value of several materials by measuring the rate at which temperature decreases as heat is lost.

Equipment:

1. Graduated cylinders – 250 ml
2. Thermometer
3. Timer or stop watch
4. Several cups
   a. Paper
   b. Ceramic
   c. Glass
   d. Metal (tin, aluminum, steel)
   e. Plastic
   f. Styrofoam

Procedure:

1. Students will work in groups of four (each student will analyze the cooling of a different cup.
2. Students may need to check the accuracy of their thermometers by placing them in constant temperature water baths.
   a. Ice water bath at 0 °C.
   b. Boil water at Temp 99-100 °C
3. Place the same amount of water (200 ml) into each of several different kinds of cups (70-80 °C heated water) (students need a hot pad)
4. Read the temperature of the water after it equalizes.
5. Read the temperature of the water in the cup every 30 seconds for 12-15 minutes. (Make certain cups are spread apart so all cool at about the same rate).
6. Record temperature versus time and graph the results. Draw a line of best fit (best straight line).
   a. Find the slope of each graph. (This slope will be negative).
   b. The slope will indicate the cooling rate. (The negative sign means the water is cooling down).
   c. Students will need to review the concept of slope as it relates to a rate of change. (Units will be °C per minute).
7. Graph the data on the graph paper provided.
8. The graph that shows the fastest drop to the right (steepest slope) is the one that represents the fastest rate of cooling. This is therefore the cup that loses the most heat per minute and is the poorest insulator.

Lab 2 – Heat Loss (Measuring the Rate of Cooling) – Student Edition

Data:

Time	Cup 1	Cup 2	Cup 3	Cup 4
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				

15 minutes of cooling

Lab 3 – Heat Loss (Measuring the Rate of Cooling -Second) Student Edition

Purpose:

To determine the effect, if any, of the difference in temperature between the inside and the outside of the cup that is the poorest insulator. (We will determine the effect a difference in temperature on the two sides of a poor insulator has on the rate of cooling.)

Equipment:

1. Cup that is the poorest insulator (one that loses heat the fastest).
2. Supplies of water at proper temperatures.
3. Graduated cylinder (250 ml).
4. Thermometer.
5. Timer.
6. Oven mitts or paper towels.

Procedure:

1. Use the same amount of water in each trial (200 ml)
2. Use the same cup or identical cups that allow a hot liquid to cool rather quickly.
3. First, start with hot water (95 to 100° C)
4. Second, water at 60-65° C
5. Third, water at 35-38° C
6. Record the temperature for the three different situations as in the first rate of cooling experiment. (record the temperature every 30 seconds).
7. Graph the data from each trial on the same piece of graph paper.

Data:

Time	95-100° C Water	60-65°	35-37°
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			

15			
16			
17			
18			
19			
20			

Calculations:

1. Graph the data on the graph paper provided and find the slope of each line. (What is the meaning of each slope)?
2.

Calculations	95-100°C	60-65°C	35-37°C
Slope			

Show sample calculations for the 95-100°C trial.

Calculations	95-100°C
Slope	

Lab 3 – Heat Loss (Measuring the Rate of Cooling -Second) Student Edition

Conclusion:

1. What is the meaning of the three graphs if they are all parallel?
2. What is the meaning if some of the graphs slope upward to the right?
3. What is the meaning of a graph that is parallel to the x-axis?
4. What is the meaning of three graphs that have different slopes?
5. Would you expect a large difference or a small difference in this experiment?
6. How could the graph be changed to show small differences more distinctly?
7. What conclusions did you reach? Does hot water cool faster or slower than cool water?

Lab 4 – Introduction to Heat Measurement - Student Edition

Purpose:

We need to be able to distinguish heat from temperature. Making this distinction allows us to use heat as a measure of energy. We need to use changes in temperature to calculate changes in heat energy.

Background:

Heat energy (Q) = Mass of material (grams) • change in temp • specific heat
ΔT C (calories C=1)

We should find the mass of the water used (more accurate) than using volume.
The starting temperature may be any value (each student may select his/her own starting temperature – makes for a good experiment). – The student makes up his/her own starting temperature somewhere between 1-8°C.

Equipment:

1. Styrofoam cups (large)
2. Thermometers – 10 to 110 °C
3. Graduated cylinders – 100 ml
4. Supply of water of known temperature (can be dipped from pan that has stood in the lab – this water was originally between 0 and 5°C and was allowed to warm to room temperature).

Procedure:

1. Find the temperature of the 1st 100 ml sample (25° C).
2. Record an imaginary starting temperature (must be above freezing) 5°C (student pick).
3. Find ΔT 25° - 5° = 20°C
4. Need mass of water placed in cup 1 (close to 100 g).
5. Add a second (100 ml) sample to the Styrofoam cup (same as first 100 g sample).
6. Find the temperature of the water in the cup after the second sample was added.
7. Find the heat energy change for the first addition Q = 100 g • 20°C = 2000 cal
8. Find the heat energy change for the second addition
   2000 cal
9. Find the heat energy change of the water in the cup after the second addition has been made.
   2000 + 2000 = 4000 calories

Lab 4 – Introduction to Heat Measurement - Student Edition

Data:

Measurement	Cup 1	Cup2
1. Mass of cup		
2. Mass of cup + water		
3. Starting temperature – T_i		
4. Room temperature – T_{rm}		
5. Temp after 2nd addition – T_f		

Calculations:

Calculation	Cup 1	Cup2
1. ΔT for 1st addition		
2. Mass of H_2O of 1st addition		
3. Q for 1st addition		
4. Q for 2nd addition		
5. Total energy after 2nd addition		
6. Change in temperature from 1st to 2nd addition		

Sample calculation for cup 2

Calculations:

Calculation	
1. ΔT for 1st addition	
2. Mass of H_20 of 1st addition	
3. Q for 1st addition	
4. Q for 2nd addition	
5. Total energy after 2nd addition	
6. Change in temperature from 1st to 2nd addition	

Conclusion:

We found that if we add more water of the same temperature we increased the heat content but did not raise the temperature. How do we explain this observation? Reflect on our class discussion and your class notes.

Lab 5 – The Calorie (A Working Definition) – Student Edition

Purpose:

1. To verify the working definition of the calorie (The amount of energy needed to raise 1 gram of water 1°C.)
2. To use the equation $Q = g \bullet c \bullet \Delta T$ to evaluate the data collected during the investigation.
3. To emphasize the fact that temperature is a measure of E_K (kinetic energy – energy of motion) and not a measure of heat.

Equipment:

1. 150 ml beaker
2. Hot plate (set on 3 or 4)
3. Thermometer
4. Distilled water
5. Balance
6. Clock

Procedure:

1. Need 1-150 ml beaker filled with different amounts of distilled water for each trial. (Measure water used in each trial in grams.)
2. Measure T_i for each beaker before heating.
3. Place all the beakers on the same hot plate (preset) for the same amount of time.

   (In the general sense the student should see all the beakers are exposed to the same heat sources, therefore, the same amount of energy in the same time frame.)
4. Amounts of water to be used in each trial (grams) – (one partner can do the first set while the second partner does set 2 – partners can share data)
   a. 20, 30, 40, 50, 60
   b. 20, 40, 60, 80, 100
5. Heat all the beakers for the same amount of time. (2 minutes) – The student should get a good ΔT for the beakers with the smallest amount of H_2O.
6. Measure T_f in all the beakers (at the end of 2 minutes).
   (Ask students which beaker received the greatest amount of heat energy.)
7. Use $Q = \text{grams} \bullet C \bullet \Delta T$ to calculate the heat energy transferred to the water (appearing as E_K) in each beaker.
   Do an average and calculate a percent difference with respect to the average.
   Discuss sources of error involved in doing this investigation.
8. See if you can graph the data and come up with anything meaningful.

Lab 5 – The Calorie (A Working Definition) – Student Edition

Data: (20, 30, 40, 50,60 ml)

Measurements	Trial 1 (20 ml)	Trial 2 (30 ml)	Trial 3 (40 ml)	Trial 4 (50 ml)	Trial 5 (60 ml)
1. Mass of beaker					
2. Mass beaker + water					
3. Initial temperature T_I					
4. Temperature final (T_f)					
5. Time heated					

Data: (20, 40, 60, 80,100 ml)

Measurements	Trial 1 (20 ml)	Trial 2 (40 ml)	Trial 3 (60 ml)	Trial 4 (80 ml)	Trial 5 (100 ml)
1. Mass of beaker					
2. Mass beaker + water					
3. Initial temperature T_I					
4. Temperature final (T_f)					
5. Time heated					

Calculations for 20, 30, 40, 50, 60 ml

Calculation	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
1. Mass of water					
2. ΔT for water					
3. Specific ht of water					
4. Heat absorbed by each beaker					

Show a sample calculation for trial 2

Calculation	Trial 2
1. Mass of water	
2. ΔT for water	
3. Specific heat of water	
4. Heat absorbed by the beaker	

Lab 5 – The Calorie (A Working Definition) – Student Edition

Calculations for 20, 40, 60, 80, 100 ml

Calculation	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
1. Mass of water					
2. ΔT for water					
3. Specific heat of water					
4. Heat absorbed by each beaker					

Show a sample calculation for trial 4

Calculation	Trial 4
1. Mass of water	
2. ΔT for water	
3. Specific heat of water	
4. Heat absorbed by the beaker	

Conclusion:

1. Where does the energy for the hot plate come?
2. What energy changes occur in the hot plate?
3. Where does the energy from the hot plate transfer?
4. What happens to the water as energy is transferred from the hot plate?
5. Are energy (heat and electricity in our case) and temperature the same thing?
6. What overall energy conversions are occurring from the generating plant to the final results of our experiment?
7. How did you calculate the heat absorbed by the water?

Lab 5 – The Calorie (A Working Definition) – Student Edition

Lab 6 – How to Check Up on Heat Measurement – Student Edition

Purpose:

To make heat measurements that will allow the student to determine the final temperature of the system when hot and cold water are mixed together.

Background:

The energy change in any heat experiment done with proper insulation may be expressed as:

Energy gained = energy lost (1st law)

(The losses of heat energy should be small if good calorimeters are used.)

Heat is measured (calculated) using the following formula:

$$Q = \text{grams} \bullet \Delta T \bullet \text{specific heat}$$

We are going to fill 2 calorimeters with equal amounts of water (90-100 ml) at different temperatures. (We will measure the mass of the water in addition to its volume).

We can use $Q = g \bullet \Delta T \bullet C$ to predict the temperature that should result when the two samples are mixed using the concept that heat lost equals heat gained.

Students will compare the temperature predicted with the temperature actually measured after mixing.

Equipment:

1. Styrofoam cups (calorimeter).
2. Graduated cylinder
3. Thermometer
4. Balance
5. Water samples of different temperatures

Procedure:

1. Find the mass of a Styrofoam cup #1.
2. Fill the cup less than ½ full of room temperature water and find the mass of the cup and water. (add 90-100 g water).

3. Measure the volume of water that is equal to that used in part 1 – should be 10 °C lower (this water needs to be prepared in advance – mix ice and water).
   a. Need mass of cup 2.
   b. Need mass of cup 2 and cold water.
4. Need to calculate the temperature expected to be reached when cup 1 is mixed with cup 2.

   Heat lost = heat gained
   Grams hot • ΔT (hot) = Grams cold •ΔT(cold)
   ($T_{hot} - T_{eq}$) ($T_{cold} - T_{eq}$)
   (Solve this equation for T_{eq}

5. Record the value from the experiment.
6. Do a % error (absolute and %).
7. Do a second trial but have cup 2 warmer than room temperature.

Data:

Measurements	Part 1 (Rm temp + Colder Water) 10°C		Part 2 (Rm temp + Warmer Water) 40°C	
	Trial 1	Trial 2	Trial 1	Trial 2
Mass Cup 1				
Mass Cup 1+ Water				
T_i Cup 1				
Mass Cup 2				
Mass Cup 2 + Water				
T_i Cup 2				
T_{eq}				

Calculations:

Calculations	Part 1		Part 2	
	Trial 1	Trial 2	Trial 1	Trial 2
T_{eq} based on using an average				
T_{eq} based on heat lost = heat gained				
Absolute error				
% error				

Show sample calculations for part 1, trial 1 and part 2, trial 2

Calculations	Part 1 Trial 1	Part 2 Trial 2
T_{eq} based on using an average		
Predicted based on heat lost = heat gained		
Absolute error		
% error		

Extensions (for more capable students):

1. What if we used twice as much water of one temperature as water of the other temperature?
   a. Predict the equilibrium temperature.
   b. Perform the experiment, check it and calculate the error.
2. Predict the temperature when 3 equal volumes of water each at a different temperature are mixed (perform experiment).
3. Predict the temperature when 3 unequal volumes (masses) of water are mixed each at a different temperature (perform experiment).

Conclusion:

Write a type 1 response (use 1 or 2 of these to write the type 1 response):

1. In 10 lines or more write down things you know, things you think you know or questions you have about this investigation (activates prior knowledge).
2. Based on this experiment, write down three things that were interesting, two things that were confusing and one thing you would like to know more about. (Allow students to reflect.)
3. What happens when hot stuff is mixed with cooler stuff? (Allows students to make connections.)
4. When I write the test, what questions might I ask which might require a short written answer? (Allows student to think about learning.)

Lab 7 – Mixing Hot Water and Cold Water – Student Edition

Purpose:

To find the effect of mixing two equal volumes (or equal masses) of water at two different temperatures (Students will use very hot and very cold water).

Procedure:

Part 1

1. Find mass of calorimeter.
2. Find mass of calorimeter + addition of ≅ 100 g of cold water 5-8 °C
3. Find T_i for the cold water.
4. Repeat steps 1-3 with very warm water (80-90°C) Heat 100 ml and pour directly into calorimeter
5. Pour water together into 2nd cup, stir, and find the equilibrium temperature (pour cold water into hot water).
6. Does equilibrium agree with the predicted value?

Data – Part 1

Measurements	Trial 1	Trial 2
Mass of Cup 1		
Mass of Cup 1 + cold water		
T_i - Cup 1		
Mass of Cup 2		
Mass of Cup 2 + warm water		
T_i - Cup 2		
Teq – system		
Predicted value		

Show work to predict T_{eq}

<u>Predicted Calculation – (Heat Lost = Heat Gained)</u>

Calculations:

Calculations	Trial 1	Trial 2
1. Mass of cold water		
2. ΔT for cold water		
3. Q for cold water (heat gained)		
4. Mass of warm water		
5. ΔT for warm water		
6.Q for warm water (heat lost)		
7. Difference between heat lost and heat gained		
8. % difference		
9. Difference between the predicted and measured T_{eq}		
10. % error in T_{eq}		

Lab 7 – Mixing Hot Water and Cold Water – Student Edition

Need sample calculations here Trial 1 or Trial 2

Calculations	Trial _____
1. Mass of cold water	
2. ΔT for cold water	
3. Q for cold water (heat gained)	
4. Mass of warm water	
5. ΔT for warm water	
6.Q for warm water (heat lost)	
7. Difference between heat lost and heat gained	
8. % difference	
9. Difference between the predicted and measured T_{eq}	
10. % error in T_{eq}	

Conclusion:

1. When you think about mixing very hot and very cold water together what are some of the things you wonder about?
2. How was this type of experiment similar to another type of experiment we have already accomplished? How is it different?
3. Describe a pitfall to avoid when doing this experiment.

Lab 8 – Mixing Hot Water and Cold Water II – Student Edition

Purpose:

To find the effect of mixing unequal amounts of hot and cold water.

Procedure:

Same as previous experiment but change the amounts of hot and cold water used. (All students will select their own values).

1. Find mass of calorimeter.
2. Find mass of calorimeter 1/3 full of cold water, 5-8°C (50 to 75g)
3. Find T_i for the cold water.
4. Repeat steps 1-3 with very warm water, 90°C (100 to 125 g)
5. Pour water together into 2nd cup, stir and find the equilibrium temperature (pour cold water into hot water).
6. Does equilibrium agree with predicted value?
7. Do a second trial and reverse the amount of cold and hot water.
8. % difference = the difference between values/the average of values.

Data:

Data	Trial 1	Trial 2
1.Mass of cup 1		
2. Mass of cup1 + cooler water		
3. T_i – cooler water		
4. Mass of cup 2		
5. Mass of cup 2 + hot water		
6. T_i – hot water		
7. T_{eq} - mixture		

Show work for predicted value here for Trial 1 and Trial 2

Trial 1	
Trial 2	

Lab 8 – Mixing Hot Water and Cold Water II – Student Edition

Calculations:

	Trial 1	Trial 2
1. Mass of water – cup 1		
2. Δ T for water – cup 1		
3. Heat gained by water in cup 1		
4. Mass of water – cup 2		
5. ΔT for water in cup 2		
6. Heat lost by water in cup 2		
7. Difference		
8. % difference		
9. Predicted T_{eq} from initial measurements		
10. % error in T_{eq}		

Need sample calculations here Trial 1 or Trial 2

Calculations	Trial ______
1. Mass of cold water	
2. ΔT for cold water	
3. Q for cold water (heat gained)	
4. Mass of warm water	
5. ΔT for warm water	
6.Q for warm water (heat lost)	
7. Difference between heat lost and heat gained	
8. % difference	
9. Difference between the predicted and measured T_{eq}	
10. % error	

Lab 8 – Mixing Hot Water and Cold Water II – Student Edition

Conclusion:

1. How far was your experimental T_{eq} from ideal conditions?
2. What sources of error could have affected your final results?
3. How did the % difference compare to the % error?
4. What is the difference between a % error and a % difference?

Lab 9 – Mixing Hot Water and Cold Water III – Student Edition

Purpose:

To re-emphasize the difference between heat energy and temperature when unequal volumes at the same temperature are mixed.

Equipment:

1. Styrofoam calorimeter
2. Thermometers
3. Balance or graduate
4. Warm water (supply of)

Procedure:

1. Combine unequal volumes of water at the same temperature.
2. Carefully measure the quantity of water with a graduate or balance.
3. Pour 30 ml of warm water into calorimeter cup 1 (more if cup is larger) . Record the temperature.
4. Pour in 60 ml or twice the first volume into the same cup. Record the temperature.
5. For Trial 2 reverse the amounts of warm and cold water.

Data:

Measurement	Trial 1	Trial 2
1. Volume 1st warm water		
2. Volume 2nd warm water		
3. Temp of 1st volume		
4. Temp of 2nd volume		
5. Temp of mixture		
6. Volume of mixture		

Lab 9 – Mixing Hot Water and Cold Water III – Student Edition

Conclusion:

1. Were the temperature of the warm water put into the cup the same?
2. How does the available energy from 60 ml of water compare with the energy available from 30 ml (both at the same temperature)?
3. When we add a supply of water that has twice the energy and twice the mass why does the temperature not rise?

Lab 10 – Calorimeter Constant – Student Edition

Purpose:

To determine the calorimeter constant for a double cup Styrofoam constant pressure calorimeter.

Background:

- The calorimeter is an insulated container that can be used to study chemical and physical changes that involve changes in energy. These changes are allowed to occur inside the calorimeter and measurements of mass and changes in temperature allow the user to calculate the heat exchange that occurs.

- The use of this device is based on the first law of thermodynamics (Law of Conservation of Energy). Based on the principle that, "Energy can neither be created or destroyed but may be converted from one form to another". In our experiments the heat lost or gained in a physical or chemical change will be equal to the heat lost or gained by the solution in the calorimeter.

- Because no system is perfect, some of the energy transferred is absorbed or lost by the material that makes up the calorimeter.

- Background for procedure:
  1. We will mix hot and cold water (know mass).
  2. Determine the equilibrium temperature and the change in temperature (ΔT).
  3. We will calculate the energy lost and energy gained.
  4. Relationship:

     $$\Delta Q_{Hot} = \Delta Q_{cold} + \Delta Q_{calorimeter}$$

     (cal. absorbs some of the heat from hot water)
  5. We will find the energy gained or lost by the calorimeter.
     a. Unit (calories/°C)
     b. Unit (Joules/°C)
     c. The calorimeter constant represents the amount of energy absorbed or lost by the calorimeter for every 1°C change in temperature.
  6. To calculate this constant we use the following formula.

     $$\text{Calorimeter constant} = \frac{\Delta Q_{hot} - \Delta Q_{cold}}{\Delta T_{hot}} = \frac{\text{calories}}{°C}$$

     We can do this trial, determine the calorimeter constant and use the calculated value in subsequent experiments.

Lab 10 – Calorimeter Constant – Student Edition

Equipment:

1. 2 calorimeters
2. Balance
3. 10 ml graduate or 10 ml syringe
4. Cold tap water
5. Warm tap water
6. 2 thermometers
7. Paper towel

Procedure:

1. Label calorimeters (cold water – warm water)
2. Find the mass of each calorimeter.
3. Add 60 ml of (7-10°C) cold water to proper calorimeter.
4. Add 60 ml of (40-45°C) hot water to proper calorimeter.
5. Find the mass of each calorimeter and its water.
6. Measure the temperature of each sample of water.
7. Pour the cold water into the warm water and record the equilibrium temperature (T_{eq})
8. Repeat the experiment to verify the results.

Data:

Measurements	Trial 1	Trial 2	Trial 3
1.Mass of cold water calorimeter			
2. Mass of cal + cold water			
3. T_i cold water			
4. Mass of warm water calorimeter			
5. Mass of cal. + warm water			
6. T_i warm water			
7. Final temp after mixing T_{eq}			

Calculations:

Calculations	Trial 1	Trial 2	Trial 3
1. Mass of cold water			
2. Cold water ΔT			
3. Mass of warm water			
4. Warm water ΔT			
5. Energy gained (Q) by the cold water			
6. Energy lost (Q) by the warm water			
7. Absolute difference $\|\Delta Q_{warm} - \Delta Q\|_{cold})$			
8. Calorimeter constant			
9. Average calorimeter constant			

Sample calculations for trial 2 (next page).

Calculations:

Calculations	Trial 2
1. Mass of cold water	
2. Cold water ΔT	
3. Mass of warm water	
4. Warm water ΔT	
5. (Q) Energy gained by the cold water	
6. (Q) Energy lost by the warm water	
7. Absolute difference $\lvert \Delta Q_{warm} - \Delta Q \rvert_{cold})$	
8. Calorimeter constant	
9. Average calorimeter constant	

Conclusion:

1. Why did we do this investigation?
2. How did constants compare lab station to lab station?
3. When will we use this calculated value?

Lab 11 – The Mechanical Equivalent of Heat – Student Edition

Purpose:

To determine the mechanical equivalent of heat (1 calorie = 4.187 Joules)
Universal measure of energy

History:

Benjamin Thompson (Count Rumford) 1753 to 1814

- At this point scientists (natural philosophers) believed mechanical energy and heat were two different things.
- Thompson was hired by the Elector of Bavaria to make cannons. From Thompson's perspective the work put into turning the drill seemed to disappear rather than becoming stored as E_p or E_k. The drill and the cannon got hot with no apparent source of heat.
- Thompson suggested that the work done on the cannon (force applied over a distance) was the source of the heat. The mechanical work was changed into heat energy through the process of friction. Therefore, heat was not separate (work was converted to heat energy).

James P. Joule (1818 to 1889 – Does the quantitative work to establish the relationship between work and heat.

- With some unique apparatus he was able to transform a known amount of work into a measurable quantity of heat.
- Joule showed:
  - Heat was a form of energy
  - Calories and Joules were different sized units of the same thing and could be converted (1 calorie = 4.187 Joules)
  - His investigations determined the mechanical equivalent of heat. His devices did a know amount of work against friction and in the process measured the amount of heat produced.

Background – Theory:

In our device two surfaces slide over one another (nylon rope over copper drum)

1. A force of friction (F_f) arises parallel to the surface.
2. The F_f must be opposed by an equal parallel-applied f force if motion at a constant speed (angular) is to be maintained.
3. The applied force does work equal to the magnitude of the weight lifted times the distance through which that force moves in pushing one surface over the other.
4. The work done is not stored as E_p and does not appear as an increase in E_K of the moving body.

5. The sliding surfaces get hot (friction) and this friction transforms mechanical work into heat (a different form of energy).
6. Joule collected evidence that the amount of heat that appears is proportional to the work done against friction.
7. This experiment will allow the student to do work to lift the 5 Kg mass, which will translate into friction that heats the system and therefore allows us to measure the heat produced.
8. Our device – For demo purposes
   a. A nylon rope (cord) wrapped around a Cu calorimeter with a 5.0 kg mass hanging from the other end.
   b. A hand crank turns the drum and the user attempts to hoist the 5.0 kg mass. (However, the nylon rope slips on the drum but there is enough friction to suspend the 5.0 kg mass off the floor.)
   c. The friction between the rope and the drum produced by the work being done to try to lift the 5.0 mg mass is converted to heat energy, which raises the temperature of the cu calorimeter and the water inside.
   d. The 5.0 kg mass (49.85 N) $F_{(w)}$ = mg is the force that is overcome by the crank and is equal to the force of friction.
   e. The distance through which this force acts is equal to the distance moved by any point on the drum.
      i. $D = \pi \bullet d \bullet rev.$
      ii. Work = mg x distance (force = weight = mg)
      iii. Work = (mg) (π d rev)
   f. The Cu calorimeter (drum) is insulated from the base by a plastic holder.
      i. The nylon cord is in thermal contact (frictional contact) with the drug.
      ii. The Cu calorimeter is filled with water.
      iii. A thermometer is inserted into the calorimeter to monitor the temperature of the water and Cu.
   g. The heat produced by the frictional work is transferred to the water and Cu. Using $Q = g \bullet c \bullet \Delta T$ we can calculate the heat produced from this frictional work.
   h. When measurements are taken and calculations of work done and heat produced are completed, find the ratio

$$\frac{\text{Heat produced } (H_20 \text{ and Cu})}{\text{Work done}} =$$

Lab 11 – The Mechanical Equivalent of Heat – Student Edition

Procedure:

1. Label the diagram of the apparatus.
2. Find the mass of the calorimeter and sealing ferule.
3. Fill the calorimeter with distilled water and find the mass.
4. Use a Vernier caliper to find the diameter of the Cu calorimeter.
5. Insert the thermometer through the seal into the drum and tighten the sealing ferule.
6. Set up the apparatus.
   a. Anchor the device to the corner of a table (right front)
   b. Attach the 5.0 kg mass to the end of the nylon rope.
   c. Have the calorimeter and water 3.0° C ≅ below room temperature.
   d. Measure the initial temperature of the water and calorimeter.
   e. Crank the handle 50 turns at a time (the 5.0 kg will lift off the floor) and record the rise in temperature every 50 turns).

Data:

Measurements	Trial 1	Trial 2
1.Mass of calorimeter		
2. Mass of calorimeter plus water		
3. Initial temperature of room (T_I)		
4. Initial temperature of water + Copper calorimeter		
5. Temperature after 50 turns		
6. Temperature after 100 turns		
7. Temperature after 150 turns		
8. Temperature after 200 turns		
9. Temperature after 250 turns		

Calculations:

1. Calculate the work done on the 5.0 kg mass in the attempt to lift it some distance (250 turns)

Calculation	Trial 1	Trial 2
1. Distance lifted		
2. Weight lifted		
3. Force of friction		
4. Work done		

Lab 11 – The Mechanical Equivalent of Heat – Student Edition

Do the sample calculations for trial 1.
Sample Calculations:

Calculation	Trial 1
1. Distance lifted	
2. Weight lifted	
3. Force of friction	
4. Work done	

2. Calculate the heat energy that was produced by the frictional work and absorbed by the copper calorimeter and water.

Calculation	Trial 1	Trial 2
1. Heat absorbed by copper calorimeter		
2. Heat absorbed by water		
3. Total heat absorbed		

Show a sample calculation for trial 1

Calculation	Trial 1
1. Heat absorbed by cooper calorimeter	
2. Heat absorbed by water	
3. Total heat absorbed	

3. Calculate the ratio:

Calculation	Trial 1
1. Work done/heat absorbed	

Lab 11 – The Mechanical Equivalent of Heat – Student Edition

Conclusion:

In 10-15 lines or more write the things you know, things you think you know and questions you have about the mechanical equivalent of heat.

Lab 12 – Mechanical Equivalent of Heat (Second Technique) – Student Edition

Calculations:

	Trial 1	Trial 2	Trial 3
Total potential energy of buckshot			
Temperature change			
Specific heat of buckshot			
Calories gained by buckshot			
Mechanical equivalent of heat, experimental			
Mechanical equivalent of heat, accepted value			
% error			

CALCULATIONS
Show the calculations for Trial 1 in the spaces provided below. Enter the results of the calculations for all trials in the calculations table.

Calculations:

	Trial 1
Total potential energy of buckshot	
Temperature change	
Specific heat of buckshot	
Calories gained by buckshot	
Mechanical equivalent of heat, experimental	
Mechanical equivalent of heat, accepted value	
% error	

Lab 12 – Mechanical Equivalent of Heat (Second Technique) – Student Edition

Conclusion:

1. Write down two things you found interesting about this investigation.
2. What were two or more things you found a bit confusing?
3. What part of this experiment would be difficult to explain to someone else? Why?
4. Based on answers to 1, 2 and 3, what things do you know, what do you think you know and what questions do you have?

Lab 13 – Specific Heat of a Metal – Student Edition

Purpose:

To experimentally determine the specific heat of copper and aluminum and then use the procedure to determine the specific heat of an unknown metal and identify the metal from this value.

Background:

- Specific heat c is defined as the amount of heat energy (Joules or calories) needed to raise 1 gram of a substance 1°C. This value is a characteristic property of a substance and if carefully measured can be used to identify that substance.
- In this investigation:
  1. Various metals will be heated to between 95 and 98°C using steam.
  2. These metals will then be placed in a prepared calorimeter where the metal will lose its energy to the water and calorimeter.
  3. Using the method of mixtures, students will base calculations on heat lost (by the metal), will equal heat gained by the water and calorimeter.
  4. With careful measuring and attention to detail, students will be able to calculate the specific heat of the metal.

$$Q = g \bullet \Delta T \bullet c \text{ (specific heat)}$$

Procedure: (Using the steam boiler)

1. Find the mass of the metal used.
2. Measure the T_i of the metal – (after it has been heated).
3. Measure the mass of the calorimeter cup (use Styrofoam or aluminum).
4. Measure the mass of the calorimeter cup and water (1/2 to 2/3s full of water).
5. Find the initial temperature of the water.
6. Find the equilibrium temperature after the hot metal is poured into the water and the system is allowed to come to a steady state.
7. Calculate the heat gained by the water.
8. Calculate the heat gained by the calorimeter.
9. Write an equation for the heat lost by the metal.
10. Heat gained by the water + heat gained by calorimeter = heat lost by cooling metal.

Lab 13 – Specific Heat of a Metal – Student Edition

Data:

Measurement	Al	Cu	X
1.Mass of heating cup			
2. Mass of cup + metal			
3. T_i – metal (after it is heated)			
4. Mass of calorimeter cup			
5. Mass of calorimeter cup + water			
6. T_i – $H_2 0$ in calorimeter			
7. T_{eq} – Cup, $H_2 0$ and metal			

Calculations:

	Cu
1. Mass of metal	
2. ΔT – metal ($T_i - T_{eq}$)	
3. Equation for heat lost by the metal	
4. Mass of $H_2 0$	
5. ΔT for $H_2 0$	
6. Heat gained by $H_2 0$– ($Q = g \bullet \Delta T \bullet c$)	
7. ΔT for cal. Cup ($T_{eq} - T_i$)	
8. Heat gained by cal. Cup (cal constant • ΔT)	
9. Total heat gained	
10. Solve for c for the metal.	
11. % error	

$$\%error = \frac{|KV = EV|}{KV} \bullet 100$$

Do sample calculations for copper below.

Calculations:

	Cu
1. Mass of metal	
2. ΔT – metal ($T_i - T_{eq}$)	
3. Equation for heat lost by the metal	
4. Mass of $H_2 0$	
5. ΔT for $H_2 0$	
6. Heat gained by $H_2 0$– ($Q = g \bullet \Delta T \bullet c$)	
7. ΔT for cal. Cup ($T_{eq} - T_i$)	
8. Heat gained by cal. Cup (cal constant $\bullet$ ΔT)	
9. Total heat gained	
10. Solve for c for the metal.	
11. % error	

Conclusion:

1. What happens to the thermal energy of the metal when it is placed in the water and calorimeter?
2. What do we assume occurs during the process discussed in question 1?
3. How much energy was lost by the metal?
4. How much energy was gained by the water and calorimeter?
5. How does the calculated c compare to the known value?
6. Are there any possible sources of error in this process?

Lab 14 – Specific Heat of a Metal (II) – Student Edition

Purpose:

1. In this experiment we will use a procedure similar to the first experiment to measure c for 5 different metals.
2. Using a streamlined process, students will measure c for Cu, Zn, Fe, Al and Sn and compare their calculations with the known value.

Background:

- Specific heat c is defined as the amount of heat energy (Joules or calories) needed to raise 1 gram of a substance 1°C. This value is a characteristic property of a substance and if carefully measured can be used to identify that substance.
- In this investigation:
    1. Various metals will be heated to between 95 and 98°C using hot water.
    2. These metals will then be placed in a prepared calorimeter where the metal will lose its energy to the water and calorimeter.
    3. Using the method of mixtures, students will base calculations on heat lost (by the metal), will equal heat gained by the water and calorimeter.
    4. With careful measuring and attention to detail, students will be able to calculate the specific heat of the metal.

$$Q = g \bullet \Delta T \bullet c \text{ (specific heat)}$$

Procedure:

1. Find the mass of the individual samples of metal.
2. Heat the metal samples in a 400 ml tall beaker until they are at the temperature of the boiling water (97-99°C).
3. Prepare 5 calorimeters each with enough water to cover the metal samples when they are placed in the calorimeter. (Aluminum will present the most problem – may need to use a larger calorimeter.)
4. Assume all the metal samples are at the temperature of the boiling water before they are placed in the calorimeter.
5. Measure the initial temperature of the water in each calorimeter just before the metal is added.
6. Add the hot metal (97-99°C) to the prepared calorimeter. Allow the system to reach thermal equilibrium and record the equilibrium temperature for each of the five systems (T_{eq}).
7. Calculate the heat gained by the water.
8. Calculate the heat gained by the calorimeter.

9. Write an equation for the heat lost by each metal that contains the unknown specific heat (c).
10. Using heat lost = heat gained, solve for the specific heat of each metal.

Data (Specific Heat of Five Samples):

Metal Used	Al	Cu	Zn	Sn	Fe
Measurement	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
1. Mass of metal					
2. T_i – metal (temperature of boiling water)					
3. Mass of calorimeter cup					
4. Mass of calorimeter cup + H_2 0					
5. T_i - H_2 0					
6. T_{eq} - H_2 0 and metal					

Calculations (Processing the Data):

Metal Used	Al	Cu	Zn	Sn	Fe
Calculations	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
1. ΔT for the metal					
2. Heat lost by the metal (will contain unknown)					
3. ΔT - H_2 0 and calorimeter					
4. Mass of H_2 0					
5. Heat gained by the water.					
6. Heat gained by calorimeter					
7. Specific heat of metal					
8. Known value					
9. % error					

Lab 14 – Specific Heat of a Metal (II) – Student Edition

Calculations (Processing the Data):

Calculations	Calculations for Cu
1. ΔT for the metal	
2. Heat lost by the metal (will contain unknown)	
3. ΔT - H_2 0 and calorimeter	
4. Mass of H_2 0	
5. Heat gained by the water.	
6. Heat gained by calorimeter	
7. Specific heat of metal	
8. Known value	
9. % error	

Lab 14 – Specific Heat of a Metal (II) – Student Edition

Conclusion:

1. What happens to the thermal energy of the metal when it is placed in the water and calorimeter?
2. What do we assume occurs during the process discussed in question 1?
3. How much energy was lost by the metal?
4. How much energy was gained by the water and calorimeter?
5. How does the calculated c (specific heat) compare to the known value?
6. Are there any possible sources of error in this process?

Lab 15 – Temperature of a Hot Body – Student Edition

Purpose:

To use the principles of heat exchange to determine the initial temperature of a red-hot piece of metal.
(The energy present in the red-hot metal will be absorbed by the water in a prepared calorimeter as well as by the calorimeter).

Procedure:

1. Set up a steam boiler to be used as a holder for the piece of metal to be heated.
2. Using a coat hanger, prepare a piece of wire that will suspend the iron sample in a gas burner flame.
3. While the metal is being heated, prepare a metal calorimeter (Al) that is 2/3s full of 5.0°C water.
4. When the metal is red-hot (turn off room lights), dump the sample into the prepared calorimeter. (There will be some bumping.)
5. Allow the system to reach thermal equilibrium and reach the equilibrium temperature (T_{eq}).
6. Calculate the energy absorbed by the water.
7. Calculate the energy absorbed by the calorimeter (Al).
8. Write an equation that addresses the heat lost by the iron sample that includes ΔT as X for the unknown term.
9. Using heat lost = heat gained solve the expression for the ΔT for the iron sample.
10. Add $\Delta T + T_{eq}$ and find the T_i for the red-hot metal. Convert the temperature to:

    $F = (9/5C) + 32$

Lab 15 – Temperature of a Hot Body – Student Edition

Data:

Measurements	Trial 1	Trial 2
1. Mass of the Fe sample		
2. Specific heat of Fe		
3. Mass of cal. Cup (Al)		
4. Mass of cal. Cup + H_20.		
5. T_i of H_20		
6. T_{eq} of system (metal, H_20 and cal cup)		

Calculations:

Calculations	Trial 1	Trial 2
1. Mass of H_20		
2.ΔT for H_20 + cal cup		
3. Heat gained by H_20		
4. Heat gained by cal cup		
5. Total heat gained by system		
6. Expression for heat lost by metal		
7. ΔT for hot metal sample		
8. T_I for hot-body T_{eq} + $\Delta T = T_I$		
9. T_I for hot body in °F		

Do the sample calculations on the next page for trial of your choice.

Lab 15 – Temperature of a Hot Body – Student Edition

Calculations:

Calculations	Trial 1
1. Mass of H_20	
2. ΔT for H_20 + cal cup	
3. Heat gained by H_20	
4. Heat gained by Al cal cup	
5. Total heat gained by system	
6. Expression for heat lost by metal	
7. ΔT for hot metal sample	
8. T i for hot-body T_{eq} $\Delta T = T_i$	
9. T_i for hot body in °F	

Lab 15 – Temperature of a Hot Body – Student Edition

Conclusion:

Lab 16 – Phase Changes (Freezing and Melting) – Student Edition

Purpose:

1. To qualitatively analyze what happens to water when it freezes to form ice.
2. Additionally observe what happens when ice that formed is melted to reform the water.
3. Repeat the experiment and quantitatively analyze what happens to the water when it is frozen and when it is allowed to return to its liquid state.

Equipment:

1. 250 ml beaker
2. 20 X 150 test tube
3. Thermometer
4. Rock salt or ice melt (KCl)
5. Ice
6. Tap water

Procedure:

Part I (Qualitative) – You may want to ignore this section and do part II only

1. Place 1-2 ml of tap water in test tube. Place the test tube in a beaker that has a mixture of rock salt and ice. (Can use ice melt and water).
2. Make a list of all qualitative observations that occur while the cooling process is occurring. (What do you think is happening?)
3. Remove the test tube with the ice in it from the rock salt and ice mixture and place it in a beaker of room temperature water.
4. Make observations of what is happening while the test tube is warming.
5. After you complete the cooling and warming processes explain (using your own thoughts) what you think is happening to the water and ice in both processes.

Part II (Quantitative)

1. Place 1-2 ml of tap water in a test tube and place a thermometer in the test tube. (Use a #2 one-hole stopper to center the thermometer in the test tube and record the initial temperature of the water.)
2. Place the test tube and water in the beaker of rock salt and ice and read the temperature of the system at 15-second intervals for 10 minutes. (Place a second thermometer in the rock salt and ice mixture and record the temperature of the ice bath.)

3. Remove the test tube from the rock salt and ice and place the test tube in a beaker of room temperature water reading the temperature every 15 seconds for 10 minutes. (Use a second thermometer to measure the water temperature in the beaker.)
4. Graph the results of steps 2 and 3 (temperature as a function of time).

Data – Part I – Observations:

1.
2.
3.
4.
5.

Data: Part II: (Sample data is included on the last page). Graph is included on 4th page

Freezing		Melting	
Time-Freezing	Temperature-Freezing	Time – Melting	Temperature-Melting
1		1	
2		2	
3		3	
4		4	
5		5	
6		6	
7		7	
8		8	
9		9	
10		10	
11		11	
12		12	
13		13	
14		14	
15		15	
16		16	
17		17	
18		18	
19		19	
20		20	
21		21	
22		22	
23		23	

24		24	
25		25	
26		26	
27		27	
28		28	
29		29	
30		30	
31		31	
32		32	
33		33	
34		34	
35		35	
36		36	
37		37	
38		38	
39		39	
40		40	

Conclusion:

1. How did Part II differ from Part I?
2. What happens to the system's temperature when the water freezes? When the ice melts?
3. What do you think is happening to the energy that is being exchanged in both systems? (What happens to the heat energy as the water freezes in the first situation and ice melts in the second situation?)

Lab 17 – Heat of Fusion – Student Edition

Purpose:

To measure the amount of heat energy (calories or Joules) associated with the change of phase of water as it changes from solid to liquid phase.

$$H_20_{(S)} + \underset{(H_f)}{\text{energy}} \longrightarrow H_20_{(L)}$$

Background:

1. Fill a glass with ice (0° C) and allow it to stand in a warm room until the last bit melts. The temp is still 0° C.
   a. Temperature – not changed
   b. We know the system (glass of ice) has absorbed energy.
   c. Where did the energy go?
   d. What was the effect of this energy?
2. We can easily see ice has changed to water. Heat energy goes into the ice, breaks the bonding in the solid (hydrogen bonds) and converts ice to water.
3. L_f (latent heat of fusion) defined as the amount of heat energy required to change a unit mass (grams or mole) of a substance from solid to liquid phase.
   Ice 79.7 cal/gram
4. We can use warm water to melt ice. Logic here is that the warm water gives up heat energy that is used to melt the ice.
5. Do the heat exchange in an insulated calorimeter.
   a. In the calorimeter heat gained = heat lost
   b. Heat gained includes heat to melt ice
   c. Heat lost includes heat lost by warm water + heat lost by calorimeter (small and is sometimes ignored). Assume system cools to around 5° after all the ice melts.

Procedure:

1. Need warm water 15-20° C above room temperature (use 40-43°C tap water).
2. Note the type of calorimeter (constant pressure) that you are using.
   a. 2 Styrofoam cups with a lid (or b)
   b. Aluminum with an inner and outer cup (Do not find mass of the ring)
3. Find the mass of the calorimeter cup.
4. Add water to the cup 40-43° C and find the mass of the cup and the warm water.
5. Find the T_i for the warm water before you start to add the ice (stir water and measure the temperature).

6. Obtain your ice in a Styrofoam cup, dry the surface of the ice with a paper towel and then add to the warm water. (Do not splash).
7. Continue to add ice until the temperature is around 5°C (This is about as low as is needed), lower temperature may cause condensation on the calorimeter.
8. Control the ice addition of the end so it melts and does not need to be removed.
9. Measure the final temperature and find the mass of the calorimeter, warm water and ice (now ice water).
10. Compute the heat lost and heat gained and compute the heat of fusion.
11. Partners should work together with one another each doing their own trial.

Data:

Measurements	Trial 1	Trial 2
1. Mass of calorimeter cup		
2. Mass of calorimeter cup + warm water		
3. Mass of calorimeter cup + warm water + ice water (after ice melts)		
4. T_i - warm water + calorimeter		
5. T_f – water + calorimeter + ice water		

Calculations:

Calculations	Trial 1	Trial 2
1. Mass of warm water		
2. Mass of ice		
3. C = calorimeter		
4. ΔT – warm water + calorimeter		
5. Calories lost by calorimeter		
6. Calories lost by water		
7. Total calories lost		
8. Calories used to warm water formed by melted ice		
9. Calories used to melt ice		
10. Calories used to melt 1 gram of ice		
11. Calories used to melt 1 mole of ice		
12. Known value of H_f		
13. Absolute error		
14. % error		

Lab 17 – Heat of Fusion – Student Edition

Sample Calculation for Best Trial:

Calculations	Trial 2
1. Mass of warm water	
2. Mass of ice	
3. C = calorimeter	
4.ΔT – warm water + calorimeter	
5. Calories lost by calorimeter	
6. Calories lost by water	
7. Total calories lost	
8. Calories used to warm water formed by melted ice	
9. Calories used to melt ice	
10. Calories used to melt 1 gram of ice	
11. Calories used to melt 1 mole of ice	
12. Known value of H_f	
13. Absolute error	
14. % error	

Conclusion:

1. What happens to the temperature of the ice as you observe it change from solid to liquid?
2. What becomes of the heat energy that is used to melt the ice?
3. Why did the student dry the ice before dropping it into the calorimeter? How would the investigation be affected if the ice were not dried?
4. What is H_f - heat of fusion?
5. What is the value of H_f?
6. What are the principle sources of error in this experiment?
7. Reflect on the reason you did the investigation and if you were able to achieve the goal.

Lab 18 – Boiling Point of a Liquid – Student Edition

Purpose:

To use the laboratory setup demonstrated in class to measure the boiling points of four unknown liquids. Proper technique should allow the identification of each liquid.

Procedure:

Students will write out the procedure based on their class notes.

Students will include a diagram of the apparatus that was set up in class (imitation is the sincerest form of flattery).

Lab 18 – Boiling Point of a Liquid – Student Edition

Data: Graph data on graph paper provided or use Excel.

Time	Liquid 1	Liquid 2	Liquid 3	Liquid 4
0				
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				
35				
36				
37				
38				
39				
40				

Conclusion:

1. What happens to the temperature of each liquid as it starts to boil?

2. What is happening to heat energy from the burner as the liquid begins to boil?

3. What happens to heat energy as a vapor (gas) condenses to form a liquid?

4. If it takes longer for a liquid to boil does it mean the liquid gets hotter? Explain.

5. Do all the graphs look the same? How are they the same? How are they different?

6. Do all the graphs have a flat section? What are the temperatures of the flat section?

7. Was the temperature the same in all the test tubes once the liquid started to boil?

8. Does the boiling temperature depend on the amount of liquid used? What if you used 3 ml in one trial and 12 ml in the next trial? What would the graph of each trial look like? (sketch the graph)

3 ml

12 ml

9. What does a difference in boiling points reveal?

10. Is boiling point a characteristic property? Why?

Lab 19 – Heat of Vaporization – Student Edition

Purpose:

To observe the amount of heat energy (calories or Joules) associated with the change of phase of water as it changes from liquid to vapor phase. Measure the amount of heat associated with the vaporization of 1 gram or 1 mole of water.

$$H_20_{(liq)} \rightarrow H_20_{(gas)} + \text{energy}$$

Background

1. When water is heated and temperature rises toward the boiling point, bubbles form in the liquid (water bubbles filled with H_20) rise through the liquid and break at the surface. The formation of the bubbles is termed boiling and the breaking of the bubbles at the surface (allowing the molecules to enter the gas phase) is called evaporation. The combination of boiling and evaporation is termed vaporization.
2. We have noticed that the boiling water and the vapor are at the same temperature (100° C) – 212° F
3. It is evident that heat is being absorbed. However, the phase change occurs with no change in temperature.
4. The energy is used to do work to overcome the forces that hold the molecules together (Dipole – dipole) hydrogen bonding.
5. Additionally, the air that surrounds the vessel (end of hose) is also pushed back to make room for the escaping molecules (remember water displaces the air and is not absorbed by the air).
6. When molecules of the vapor condense back to liquid phase the extra heat that was stored in the molecular gas phase is released to the local environment (in our case, water in the calorimeter).
7. The heat of vaporization is the amount of energy (in the form of heat) needed to change 1 gram or 1 mole of water from the liquid to the gas phase with no change in temperature.
8. The heat of condensation (equal to H_{vap}) can be measured by allowing a known mass of steam at a know temperature (100° C) to condense into a known calorimeter with a known mass of water and noting the rise in temperature.
9. To evaluate the exchange we use the following expression:

   Heat lost by vapor + heat lost by $H_20(L)$ = heat gained by H_20 + heat gained by calorimeter

Lab 19 – Heat of Vaporization – Student Edition

Procedure:

1. Set up a steam boiler about 1/3 full of water.
   a. Prepare the calorimeter 2/3 full of 5°C water
   b. Record the air pressure
2. We need to set up a water trap between the boiler and calorimeter.
   a. We only want steam to enter the calorimeter.
   b. Need to prevent hot water that may condense along the way through the tube from entering the calorimeter.
   c. Water temperature will collect the condensed water and permit the steam to continue.
3. Find the mass of the empty calorimeter cup.
4. Add 5° C water to the cup and find the mass of the cup and water.
5. Measure the temperature of the steam.
6. Read T_i for the cold water, introduce the steam to the cold water and allow the temperature to rise as far above room temperature as it was below room temperature.
7. Remove the hose – allow system to reach equilibrium and read the equilibrium temperature T_{eq}
8. Find the mass of the calorimeter and water and condensed steam.
9. Compute the value of H_{vap} and compare to accepted value of 539.6 cal/gram.

Data:

Measurements	Trial 1	Trial 2
1. Mass of calorimeter cup		
2. Mass of calorimeter cup + 3-5° C water (ice water)		
3. T_i – cal + H_2O		
4. T_i – steam		
5. T_{eq} – water + cal final		
6. Mass of water + cal. cup + condensed steam		

Calculations:

Calculations	Trial 1	Trial 2
1. Mass of water		
2. Calorimeter constant		
3. Mass of steam		
4.ΔT for water and calorimeter		
5. ΔT for water from condensed steam		
6. Calories gained by calorimeter		
7. Calories gained by water		
8. Total calories gained		
9. Calories lost by water formed from condensed steam as it cools from T_i – steam to T_{eq}		
10. Calories lost by steam as it condenses at 100° C.		
11. H_{vap} of water = heat of condensation		
12. Accepted value for H_{vap}		
13. Absolute error +		
14. % error		

Sample Calculations:

Calculations	Trial 1
1. Mass of water	
2. Calorimeter constant	
3. Mass of steam	
4. ΔT for water and calorimeter	
5. ΔT for water from condensed steam	
6. Calories gained by calorimeter	
7. Calories gained by water	
8. Total calories gained	
9. Calories lost by water formed from condensed steam as it cools from T_i – steam to T_{eq}	
10. Calories lost by steam as it condenses at 100° C.	
11. H_{vap} of water = heat of condensation	
12. Accepted value for H_{vap}	
13. Absolute error +	
14. % error	

Conclusion:

1. What happens to the temperature of the water as it changes from liquid to vapor?
2. What does the heat from the gas burner do to the water in the boiler? What is this heat energy used for?
3. What happens when the water vapor from the boiler condenses in the calorimeter (2 things)?
4. What are the heat of vaporization and the heat of condensation?
5. Why did we use a water trap?
6. How would its absence affect your results?

Lab 20 – Molar Heat of Vaporization of Liquid Nitrogen
Student Edition

Purpose:

Using the conservation principle "heat lost equals heat gained" students will experimentally determine the heat of vaporization of liquid nitrogen.

Background:

In this investigation students will again apply the law of energy conservation to the vaporization of liquid nitrogen. In the investigation the energy to vaporize the liquid nitrogen will be provided by a measured amount of water in a prepared calorimeter. Heat lost by the water is used to vaporize the liquid nitrogen. From previous heat labs students should be able to write the equations for heat lost by the water and heat gained by the liquid nitrogen from their laboratory measurements (data). Additionally, students should recognize which processes are endothermic and exothermic.

With regard to safety, liquid nitrogen on skin contact can cause serious frostbite. Students are not allowed to sit during this lab as the liquid nitrogen could pool in his/her lap if it were to spill. Students must always wear their goggles and aprons. Do not stir the solution with a thermometer and make certain the thermometer is removed before the liquid nitrogen is added to the calorimeter.

Pre-Lab Discussion: (Certain concepts need to be in place for a success in this investigation)

1. Define the following terms
   a. Exothermic
   b. Endothermic
   c. First law of thermodynamics
   d. Specific heat
   e. Heat of vaporization
   f. Heat of fusion
   g. Calculation of heat energy (equation)
2. What is meant by the specific heat of water? What units are used? What is the value in terms of calories and Joules?
3. What is the equation used to calculate the heat energy released by water when the liquid nitrogen is added?
4. What is the numerical relationship between the heat energy lost by the hot water and the heat energy gained by the liquid nitrogen?
5. What is meant by heat of vaporization?
6. How would the heat of vaporization be calculated in this experiment?

Lab 20 – Molar Heat of Vaporization of Liquid Nitrogen
Student Edition

Procedure:

1. Students need to prepare the calorimeter (use the very large cups).
   a. Find the mass of a nested pair of Styrofoam cups.
   b. Add 100 ml of 65 °C water from the hot water supply to your calorimeter.
   c. Find the mass of the calorimeter and the hot water.
2. Determine the mass of a second set of Styrofoam cups (used to get liquid nitrogen).
   a. 80 ml+ of liquid nitrogen needs to be added to this cup.
   b. The liquid nitrogen will evaporate and you need to set it on a balance that is set to tell you when approximately 60 g of liquid nitrogen remains in the cup.
3. Students need to determine the temperature of the water (± .1°C) before the $N_{2\ (L)}$ is added. Do not place thermometer in liquid when adding $N_{2\ (L)}$.
   a. Quickly add the $N_{2\ (L)}$ to the water in the calorimeter.
   b. Make good observations. $N_{2\ (L)}$ will boil – sizzle and create a fog above the cup (cools water vapor in the air).
   c. Students need swirl the cups to melt any ice that may have formed.
   d. Do not put the thermometer in until all (a, b and especially c) have been accomplished.
   e. Record the final temperature of the cup and cool water. When the liquid nitrogen boils it causes some of the water to splatter and therefore the final mass is less than the initial mass. Students will average the two values and then use the average mass to calculate the heat lost by the warm water.

Data:

Data	Trial 1	Trial 2	Trial 3
1. Mass of calorimeter			
2. Mass of calorimeter & hot water			
3. Mass of 2^{nd} calorimeter			
4. Mass of 2^{nd} calorimeter & liquid nitrogen			
5. T_i – hot water			
6. T_f – cool water			
7. Mass of calorimeter & cool water.			

Calculations:

Calculations	Trial 1	Trial 2	Trial 3
1. Mass of hot water			
2. Mass of cold water			
3. Mass of $N_{2(L)}$			
4. Average mass of hot & cold water			
5. ΔT for hot water			
6. Heat energy released by hot water			
7. Total heat absorbed by $N_{2(L)}$			
8. Heat energy absorbed by $N_{2(L)}$/g			
9. Heat energy absorbed by $N_{2(L)}$/mole			
10. Known value (J/mole)			
11. Absolute error			
12. % error			

Lab 20 – Molar Heat of Vaporization of Liquid Nitrogen
Student Edition

Calculations – Sample Calculations (Do error discussion)

Calculations	Sample Calculation
1. Mass of hot water	
2. Mass of cold water	
3. Mass of $N_{2(L)}$	
4. Average mass of hot & cold water	
5. ΔT for hot water	
6. Heat energy released by hot water	
7. Total heat absorbed by $N_{2(L)}$	
8. Heat energy absorbed by $N_{2(L)}$/g	
9. Heat energy absorbed by $N_{2(L)}$/mole	
10. Known value (J/mole)	
11. Absolute error	
12. % error	

Conclusion:

Write a narrative account explaining how you did the experiment and the processes that occurred during the investigation.

Discussion of error – The following problems could occur during the process of doing this investigation. How would these problems affect the value of the calculated heat of vaporization?

1. Water in calorimeter 1 cools before the liquid nitrogen is added.

2. The liquid nitrogen continues to vaporize after the mass of ($N_{2\,(L)}$) is recorded.

3. Some $N_{2\,(L)}$ is spilled pouring it into the water.

4. Water is lost from the cup due to splattering.

5. Moisture condenses on the outside of the cup when the final mass is measured.

6. Heat is gained by $N_{2\,(L)}$ from the environment.

7. Students did not measure the final mass of water and used the initial mass of hot water in their calculations.

Lab 20 – Molar Heat of Vaporization of Liquid Nitrogen
Student Edition

Pre-Lab Discussion:

1. Define the following terms
   a. Exothermic

   b. Endothermic

   c. First law of thermodynamics

   d. Specific heat

   e. Heat of vaporization

   f. Heat of fusion

   g. Calculation of heat energy (equation)

2. What is meant by the specific heat of water? What units are used? What is the value in terms of calories and Joules?

3. What is the equation used to calculate the heat energy released by water when the liquid nitrogen is added?

4. What is the numerical relationship between the heat energy lost by the hot water and the heat energy gained by the liquid nitrogen?

5. What is meant by heat of vaporization?

6. How would the heat of vaporization be calculated in this experiment?

Lab 21 – Linear Expansion of Solids – Student Edition

Purpose:

Students will use the Introductory Physical Science, thermal expansion of solids investigation to illustrate the calculation of the coefficient of linear expansion, area expansion and volume expansion.

1. Each group should do three tubes and then pool the data.
2. Questions:
   a. What is the effect of substance on expansion?
   b. What is the effect of diameter?
   c. What is the effect of wall thickness?
   d. What is the effect of length?
   e. What is the coefficient of linear, area, and volume expansion based on the change in length and diameter?

Procedure:

1. One end of the tube is fixed in place using a clothespin. (Tape around the tube will help secure it more firmly in the clothespin).
2. The moving end is drawn down tightly on the moving end of the rod attached to a thumbtack under the plywood (See diagram and pay attention to the demonstration)
3. To measure the change in the length of the rod due to its change in temperature, an amplifying device to magnify the small change must be used. Students will use an indicator dial taped to a pin. The dial will rotate as the pin rolls.
4. The rod is pulled down securely on the pin (using the rubber band) and the pin is placed on a sandpapered fiberboard that insures that it rolls and does not slip. (In the setup the dial portion must not touch any part of the apparatus or table. The dial must be free to rotate as the pin turns due to the expansion of the rod.)
5. The rod will be heated using steam generated from boiling water. This process will cause the temperature of the rod to change 70 + °C and in the process cause it to expand in one direction (to the right).
6. Students need to set the apparatus up so it mirrors the sample setup and the diagram that is provided. When everything is set up the dial is set at 0° and the heating of water starts. Students will measure the temperature of the steam as it exits the rod (98°C) and let the rod experience 98°C for 2-3 minutes (this makes certain the rod is completely expanded).

7. Using a 25 x 200 mm test tube about ¼ full of water and boiling chips, students can produce the steam needed and not force hot water into the tube.
8. Students should note the way the thermometer is attached to the end of the tube to measure the temperature of the steam. The short piece of rubber tubing should fit loosely around both the tube and thermometer (no tight fits – consequence is pressure buildup and popping of stopper in the test tube and possible scalding by hot water).
9. Students need to measure the diameter of the pin and the tube diameter before and after heating.
10. Students need to examine the diagram provided when the tube expands the needle is rolled. If the needle rolled 360° it has moved 1 circumference with respect to its starting point on the table. However the tube has expanded a distance that is equal to twice the circumference. This means if the pin rotates 180° or ½ a turn the rod has moved 1 full turn or πD. If the pin rotates 360° or 1 full turn the rod has moved 2 πD or twice the circumference.
11. For 1° of rotation the tube will expand 2πD/360° or πD/180°. For x degrees of rotation the change in length is

$$\frac{2\pi D\,x}{360^\circ} \quad \text{or} \quad \frac{\pi D\,x}{180^\circ}$$

This value is equal to the change in length due to ΔT

12. To find the coefficient of linear area and volume expansion for each rod we use the following formulas:

$$\alpha = \frac{\Delta L}{L\,\Delta T} \qquad \gamma = \frac{\Delta A}{A\,\Delta T} \qquad \beta = \frac{\Delta V}{V\,\Delta T}$$

When

ΔL, ΔA or ΔV is the change in length, area or volume

L, A, or V is the length (from the clothespin to the pin), area or volume.

ΔT is the change in temperature of the rod

13. We will do a special case where we measure the expansion at various points along the rod using 3 dials simultaneously. This will be done after you have completed the measurements and initial calculations for your set of 5 rods. As a class we will calculate the expansion of the rod at each point, measure the length of the rod from the clamp to that point, measure T_i, T_f for the rod and then calculate α for each point that was evaluated. We can do this with one of our metal rods used in the initial trials and with a glass rod 3 times the length of the initial glass rod.

Data (Measurements and Observations):

					Trial 1			Trial 2		
Tube	Tube Dia	Pin Dia	Rod Lgth	Wall Thick	T_i	T_f	Indicator ° Turn	T_i	T_f	Indicator ° Turn
Cu										
Al										
Al										
Al										
Glass										

Calculations (Done on Excel and transferred to chart):

Calculation	Cu	Al (6mm thin)	Al (6 mm thick)	Al (8 mm thin)	Glass
1. ΔT for rod					
2. Circumference of pin					
3. Linear exp. ΔL					
4. New length					
5. Rod's initial area					
6. Rod's final area					
7. Rod's ΔA					
8. Rod's initial volume					
9. Rod's final volume					
10. Rod's ΔV					
11. α – linear					
12. γ – area					
13. β – volume					
14. Known α					
15. Known γ					

16. Known β					
17. Error in α					
18. Error in γ					
19. Error in β					
20. Ratio α: γ: β					

Sample Calculation

Calculation	Trial
1. ΔT for rod	
2. Circumference of pin	
3. Linear exp. ΔL	
4. New length	
5. Rod's initial area	
6. Rod's final area	
7. Rod's ΔA	
8. Rod's initial volume	
9. Rod's final volume	
10. Rod's ΔV	
11. α – linear	
12. γ – area	
13. β – volume	
14. Known α	
15. Known γ	
16. Known β	

17. Error in α	
18. Error in γ	
19. Error in β	
20. Ratio α: γ: β	

Questions:

1. How did the apparatus allow you to see the thermal expansion?

2. What are the factors that determine the precision of the measurements made in this experiment?

3. Can you explain in simple terms why the rod's linear expansion is equal to twice the rotation of the pin?

4. How did the α, γ, β compare in an approximate whole number ratio?

5. Could you apply the results of this investigation to any real world applications? Give examples.

Conclusion:

Lab 22 – Heat of Crystallization of Wax
Student Edition

Purpose:

Students will use calorimetry techniques to find the heat released when wax turns from a liquid to a solid. (The heat of crystallization.)

Background:

When a liquid changes to a solid (solidification or crystallization) the process releases heat energy. This is an exothermic process and is the exact opposite of the melting process where heat energy (call the heat of fusion) is released when the solid changes back to its liquid form. In the heat of fusion of ice students used a known amount of warm water to melt a known mass of ice in a calorimeter. The same technique (calorimetry) can be used if the process of crystallization is allowed to take place in a calorimeter. The heat released by the process of solidification will be absorbed by the water in the calorimeter causing the temperature of the water to increase. By calculating the total heat released by the wax sample students will calculate the heat lost per gram of wax that is the heat of crystallization.

Procedure:

1. Use a 400 ml beaker to bring 300 ml of water (add boiling chips) to a boil. When the water begins to boil control the heat the prevent bumping (formation of larger bubbles).
2. Need a 10-12 gram sample of wax in a 25 x 150 mm test tube. Determine the exact mass of the wax used before it is placed in the test tube.
3. Place the test tube of wax in the boiling water rotating the tube until the wax completely melts.
4. Prepare a calorimeter by putting 100 ml of cold water into a Styrofoam calorimeter made from 2 nested cups.
5. Using a test tube holder remove the test tube and wax sample from the boiling water. Observe the sample in a light and look for the first signs of cloudiness. (This is an indication of the start of solidification).
6. The moment solidification begins measure T_i for the water in the calorimeter and place the test tube in the calorimeter.
7. Rotate the test tube while the liquid wax solidifies and keep track of the temperature of the water. Students need to record the maximum temperature (T_f) reached by the water.

Lab 22 – Heat of Crystallization of Wax
Student Edition

Data:

Data	Trial 1	Trial 2	Trial 3
1. Mass of boat			
2. Mass of boat & wax			
3. Mass of coke can			
4. Mass of can & water (100 ml)			
5. T_i for water			
6. T_f for water			
7. Specific heat of H_20			

Calculations:

Calculations	Trial 1	Trial 2	Trial 3
1. Mass of water			
2. ΔT for water			
3. Heat gained by water			
4. Mass of wax			
5. Heat of crystallization (cal/g or J/g)			
6. Known value			
7. Absolute error			
8. % error			

Calculations – Sample Calculations:

Calculations	Sample Calculation
1. Mass of water	
2. ΔT for water	
3. Heat gained by water	
4. Mass of wax	
5. Heat of crystallization (cal/g or J/g)	
6. Known value	
7 Absolute error	
8. % Error	

Questions:

1. Explain what is meant by heat of fusion and heat of crystallization. How do they compare with one another?

2. What units are used to express these two properties?

3. What would happen to the value if the test tube were placed in the calorimeter immediately after removal from the boiling water?

Conclusion:

Lab 23 – Energy Content of Foods - Student Edition

Purpose:

Students will burn a portion of food and capture the heat energy that is released using a coke can calorimeter filled with a known mass of water. The amount of heat energy produced by burning 1.0 gram of a substance is known as the heat or combustion or the calorific value.

Procedure:

1. Find the mass of the food holder and then add the food sample.
2. Find the mass of the holder and the food sample.
3. Find the mass of the empty coke can and then add 50 ml of 6-8°C water.
4. Find the mass of the can and water.
5. The can should be placed in your insulation device and then adjusted so it is 1 inch above the food sample.
6. A thermometer needs to be suspended in the water so it does not touch the bottom of the can.
7. Record the room temperature. Students again need to heat the sample to a temperature as much above room temperature as it started below room temperature to cancel the effect of the room.
8. Light the food sample, place it under the can allowing the heat energy produced to heat the water until the food stops burning. Record T_f for the water and can.
9. Find the mass of the food holder and remaining food.
10. Repeat the investigation for a second food sample and add new water.

Lab 23 – Energy Content of Foods - Student Edition

Data (Type of food):

Data	Trial 1	Trial 2	Trial 3
	(Food)	(Food)	(Food)
1. Mass of food holder			
2. Mass of food holder & food			
3. Mass of empty can			
4. Mass of can & water (50-100 ml)			
5. T_i H_20			
6. T_m			
7. T_f $H_2 0$			

Calculations

Calculations	Trial 1	Trial 2	Trial 3
1. ΔT for water			
2. Mass of water			
3. Heat energy gained by water			
4. Grams of food burned			
5. Energy content of food in cal/g & J/g			
6. Known value			
7. % error			

Lab 23 – Energy Content of Foods - Student Edition

Calculations (Sample)

Calculations	Trial 1
1. ΔT for water	
2. Mass of water	
3. Heat energy gained by water	
4. Grams of food burned	
5. Energy content of food in cal/g & J/g	
6. Known value	
7. % error	

Questions

1. What happens to the calculated value for heat of combustion if heat escapes the apparatus and does not heat the can?

2. How did your values compare to the known value for your food type?

3. Explain what happened in this experiment?

Conclusion

Lab 24 – Heat of Combustion of Candle Wax – Student Edition

Purpose:

This investigation deals with the heat transfer from the combustion of a burning candle to a coke can (calorimeter) filled with a measured amount of water. The heat loss within the system is due to the physical and chemical changes that occur as a result of energy transformations.

Background:

Students were exposed to heat transfer during the demonstrations on conduction, convection and radiation. Additional experiments were done to measure the heat released and transferred when water vapor condenses or when ice freezes. In thunderstorms when water vapor condenses the heat of condensation is released and this energy powers the weather cell. Additionally the earth absorbs solar radiation and re-releases it to the atmosphere (greenhouse effect – short wave UV is changed to longer wave IR). Finally, in biological systems food storing the energy of photosynthesis is burned to provide energy for the organisms to use. Students will need to be able to design an insulated system that minimizes heat lost to or gained from the environment.

In this investigation heat energy from a burning candle is directed toward a coke can that contains 150 ml of water. The elevation in water temperature as the candle burns provides evidence that heat energy is being transferred. Students should be able to see the principle of heat exchange in this demonstration (heat lost = heat gained). Students will be expected to design a procedure with equipment necessary to prevent heat loss or gain from the environment. From measurements students should be able to calculate the heat of combustion of candle wax. Students will provide a diagram and explanation of their experimental technique that will eliminate heat loss or gain from the environment. (Simple insulation may not be enough – students need to use all their knowledge.)

Lab 24 – Heat of Combustion of Candle Wax – Student Edition

Procedure:

1. Find the mass of the candle and base.
2. Find the mass of the empty can.
3. Mass of the can + 150 ml of water.
4. Record the initial temperature of the room.
5. Apply your design and remember that oxygen must get to the flame.
6. Record the initial temperature of the water in the can (should be 6-8°C)
7. Heat the water to a temperature as much above room temperature as it was below room temperature. Stir the water in the can as it is heated.
8. Extinguish the flame gently – Record T_f for the water. (Temperature will continue to rise after the flame is out.)
9. Calculate ΔT.
10. Find the mass of the candle and base after the flame is extinguished. The change in mass of the candle is needed to determine the amount of wax that burns.

Data

Data	Trial 1	Trial 2	Trial 3
1. Mass of candle & base $_i$			
2. Mass of candle & base $_f$			
3. Mass of can			
4. Mass of can & water			
5. Room temperature (for ref)			
6. Initial water temperature T_i			
7. Final water temperature T_f			

Lab 24 – Heat of Combustion of Candle Wax – Student Edition

Calculations:

Calculations	Trial 1	Trial 2	Trial 3
1. Mass of water			
2. ΔT for water			
3. Specific heat for water			
4. Heat transferred to water			
5. Mass of wax that burned			
6. Heat of combustion for wax			
7. Absolute error (known value 421 J/g)			
8. % error			

Lab 24 – Heat of Combustion of Candle Wax – Student Edition

Calculations (Sample Calculations):

Calculations	Sample Calculations
1. Mass of water	
2. ΔT for water	
3. Specific heat for water	
4. Heat transferred to water	
5. Mass of wax that burned	
6. Heat of combustion for wax	
7. Absolute error (known value 421 J/g)	
8. % error	

Conclusion:

Lab 25 - Comparison of the Energy Content of Fuels – Student Edition

Purpose:

This is another approach to the heat of combustion or the calorific content of a substance. Students have analyzed candle wax and a variety of food samples. In this investigation students can use the coke can calorimeter to measure the heat energy released when various types of fuel are burned. (These substances will burn to release relatively large amounts of heat energy.)

Background:

Burning fuel is a combustion reaction between the fuel and oxygen. Our fuels are hydrocarbons that will burn to release carbon dioxide, water and heat energy. The reaction is exothermic and the heat energy released will be captured by the insulated coke can calorimeter. In this experiment students will burn available alcohols and kerosene. The alcohols are partially oxidized because they already contain oxygen while kerosene ($C_{10}H_{22}$) is not. The heat absorbed by the water is equal to the energy released by having a known amount of fuel. Students can then calculate the energy released per gram of fuel burned in cal/g or J/g. This is the heat of combustion or the calorific value of the fuel.

Procedure:

1. Find the mass of the can.
2. Add 100 ml of water to the can (6-8°C).
3. Find the mass of the can and water to allow determination of the mass of water in the can.
4. Place the calorimeter (can and water) in the apparatus and setup the initial trial.
5. Measure T_i of the water (nearest .1°C).
6. Find the mass of the fuel burner (with fuel) to the nearest 0.1 g or more accurate if possible.
7. Place the fuel burner under the can so the wick is 2-3 cm from the bottom of the can and light the burner.
8. Make certain the flame is just below the bottom of the can.
9. Heat the can until the temperature of the water is as much above room temperature as it was below at the beginning.
10. Blow out the flame, stir the water until the temperature stops rising and record T_f.
11. Remass the burner to allow determination of the mass of fuel that burned.
12. Repeat the experiment with other fuels if time permits.

Lab 25 - Comparison of the Energy Content of Fuels – Student Edition

Data:

Data	Fuel 1	Fuel 2	Fuel 3
1. Mass of pop can			
2. Mass of pop can & water			
3. Room temp (for reference)			
4. T_i – initial temp H_20			
5. T_f – final temp H_20			
6. Mass of burner (M_i)			
7. Mass of burner (M_a)			

Lab 25 - Comparison of the Energy Content of Fuels – Student Edition

Calculations:

Calculations	Fuel 1	Fuel 2	Fuel 3
1. Mass of water heated			
2. ΔT for water			
3. Heat gained by water			
4. Mass of fuel burned			
5. Calculation for heat of combustion			
6. Known heat of combustion			
7. Absolute error			
8. % error			
9. Class average for each fuel			
10. Absolute error (class)			
11. % error (class)			

Lab 25 - Comparison of the Energy Content of Fuels – Student Edition

Calculations (Sample Calculation):

Calculations	Sample Calculation
1. Mass of water heated	
2. ΔT for water	
3. Heat gained by water (equals heat lost burning fuel)	
4. Mass of fuel burned	
5. Heat of combustion	
6. Known heat of combustion	
7. Absolute error	
8. % error	
9. Class average for each fuel	
10. Absolute error (class)	
11. % error (class)	

Lab 2
Stud

Conc

1.

2.

3.

4.

1.
2.
3.
4.
5.

Conclusion:

1. Use % composition to determine the % of oxygen in each fuel. How is this percentage related to the heat of combustion?
2. Compare the heat liberated in the candle wax experiment to the heat energy from rubbing alcohol.
3. How do your results compare with the accepted value for each of the fuels? What are the sources of error in this experiment? (See if you can spot 5.)
4. List the errors in order from largest effect to smallest and indicate how the error would affect the calculated value for heat of combustion.

Error	Effect
1.	
2.	
3.	
4.	
5.	

APPENDIX E

Lab 1 – Heat Exchange: Hot Brick Placed in Cool Water – Teacher's Edition

Purpose:

Part I (Qualitative)

1. Make qualitative observations of a system that undergoes heat exchange. Place a hot brick in Styrofoam cooler containing cold water.
2. Observations are qualitative (what you see, hear, feel, smell or taste).
3. If you try to explain the process you are interpreting and are not making observations.
4. Write a type 1 response that includes your observations.

Part II (Quantitative)

1. Have a class discussion that addresses quantities that could be physically measured in this investigation.
2. Decide with lab partner what measurements will be made. (Repeat the investigation and make the measurements that interest you.)
3. Can you use these measurements to make any calculations? If you can calculate something, explain your reasoning.
4. When the class discusses everyone's work, make a record of some things you may want to try yourself.
5. Do a third trial if necessary and do any additional measuring needed.
6. Use these measurements to write a second type 1 response.

Equipment:

1. Styrofoam cooler
2. Water
3. Brick
4. Oven
5. Thermometer
6. Balance
7. Graduated cylinder larger)
8. Smaller brick samples
9. Styrofoam calorimeter (2 cups)
10. Ruler

Procedure:

1. Place warm brick in cool water (brick piece and Styrofoam cups).
2. Using only qualitative techniques (see, hear, feel, smell and taste) describe what is happening in this system.
3. Write a type 1 response that is a summary of your observations.
4. Have a class discussion that addresses what could be physically measured in this investigation (make a list).
5. Decide with your lab partner which measurements you will make. Repeat the investigation and make the measurements that interest you.
6. Use these measurements to write a type 1 summary of changes that occurred during the course of this investigation.

7. Share your work with other lab groups and see if there are some things you would like to include in your lab that you may not have accomplished.
8. Do a third trial (if needed) to make any additional measurements you think need to be accomplished.
9. Can you use these measurements to calculate anything?

Data:

Measurements	
1.	
2.	
3.	
4.	
5.	

Calculations:

Calculations	
1.	
2.	
3.	
4.	

Conclusion (Summary):

Type 1 Summary – initial experiment
Type 2 Summary – based on your measurements

Lab 1 – Heat Exchange: Hot Brick Placed in Cool Water – Teacher's Edition

(Teachers – give the students a type 2 writing assignment as an assessment tool for student reflection on this activity.)

Teacher Tips:

1. Teachers need a Styrofoam cooler and a large brick for the demonstration.
2. Students need small pieces of brick and large Styrofoam cups for their investigation
3. Heat the bricks in a drying oven and handle with tongs or hot pads.
4. Provide rulers, balances, thermometers and graduated cylinders for part II.
5. Teachers need to review the characteristics of type 1 and type 2 writing styles. These are summarized in the lab.

Lab 1 – Heat Exchange: Hot Brick Placed in Cool Water – Teacher's Edition

The following information was gleaned from the John J. Collins, Ed.D. Education Associates publication *Developing Writing and Thinking Skills Across the Curriculum: A Practical Program for Schools.*

Type 1 Writing:

- Students are encouraged to get their ideas on paper (brainstorming). This is the idea generating, recollecting, data gathering, exploring or questioning phase of the writing and thinking process.
    1. Completed in 7-10 minutes.
    2. Done individually (may be with no class discussion).
    3. Students get time to think about a topic (can quiet the room).
    4. Gives insight about how much each student knows about the topic.
    5. Can replace or precede classroom discussion.
    6. Can be used at the beginning of a unit (what do you know about this topic?)
- Sometimes teachers can have a few students read their papers and allow the class to organize the ideas (3 columns)
    1. Facts
    2. Questions
    3. Miscellaneous

  This activity makes students active listeners, as they need to categorize and evaluate ideas as they are read (students talk, listen and think about the topic under investigation).
- Format
    1. Only one draft.
    2. Use the sheet provided (names on right and type 1 on left)
    3. Students need to remember to skip lines.
- Grading
    1. See if the amount of writing was generated.
    2. Reading is optional (create atmosphere of no risk).
    3. Objective is to help students discover what they know.
    4. Grade is usually a √.

Type 2 Writing:

- Type 2 writing shows that the writer knows something about the topic or has thought about the topic; it is best used as a quiz. It is the correct answer to a teacher's prompt.
    1. Evaluation criteria; the content must be correct (ask for definitions, facts, explanations, or opinions supported with details).
    2. Spelling, punctuation and capitalization do not count.
        a. If writing is really poor, good ideas may be lost.
        b. Evaluate the content, not the way the content is expressed.
    3. Keys for successful type 2 writing.
        a. Prompt or question is clear and has a definite answer.
        b. Students make their own meaning by translating concepts into their own words.
        c. Vague question gets a vague answer and is hard to evaluate.
- Format for type 2
    1. Because its primary use is to quiz students, type 2 frequently takes the form of an essay, list or definition.
        a. Students should be encouraged to write what they know, or how they feel in response to a prompt.
        b. Students should be discouraged from adding lines or pages to pad answers. Good answers or ideas can be obscured in the fog of their own words.
        c. As students experience type 2 writing, they will learn the distinction between padding a response and using writing as a tool to develop and elaborate on ideas.
- Audience – The teacher has high expectations about the content of the writing but not about how skillfully or perfectly the content is expressed.

- Evaluation

1. Best for a question that requires a limited, specific and predictable response.
2. Questions or prompts with a number in them are good for type 2.
    a. List 3 possible causes.
    b. Define 3 of the terms on overhead.
    c. Explain the two main points.
3. Keep evaluation as simple as possible.
    a. Teacher can skim paper to find correct response.
    b. Use pass/fail.
    c. Wake up call for students.
    d. Teacher choice – need to be simple, quick and require teacher to skim written work to get correct response
4. Type 2 is quiz writing and is not used for a major test.
    a. Can be part of a report card grade.
    b. Can be used for the effort grade.
5. As the frequency of type 2 increases, the number of papers that need to be evaluated decreases.
    a. . May assign 20 writings and collect only 10.
    b. Students need to be engaged, never knowing if an assignment will be collected.

Teachers – you need to get a copy of *Developing Writing and Thinking Skills Across the Curriculum.* The distributor is the NETWORK, Inc at 136 Fenno Derive, Rowley, Massachusetts 01969, 1-800-877-5400. This booklet will address the 5 types of writing versus type 1 and type 2 that we have used in this assignment.

Lab 1 – Heat Exchange: Hot Brick Placed in Cool Water – Teacher's Edition

Type ________ Name ____________________________

	X	Temperature of the brick decreases.
	X	Brick loses heat (brick becomes cooler) loses heat to the water.
	X	Water temperature rises.
	X	Water gains heat (from the brick).
	X	Brick and water eventually reach the same temperature. (Equilibrium temperature)
	X	Some students will have additional responses.
		Measurements – (students may or may not chose to make the following measurements). Do not tell them what to measure. Let them make their own choices.
	X	
		1. Mass of brick
	X	2. Mass of cup
		3. Mass of cup and water.
	X	4. Volume of water.
		5. Cup radius or diameter.
	X	6. Oven temperature.
		7. Water temperature
	X	8. Water temperature after mixing
	X	Calculations - ? some may do some research.

Lab 2 – Heat Loss (Measuring the Rate of Cooling) – Teacher's Edition

Purpose:

To measure the insulating value of several materials by measuring the rate at which temperature decreases as heat is lost.

Equipment:

1. Graduated cylinders – 250 ml
2. Thermometer
3. Timer or stop watch
4. Several cups
   a. Paper
   b. Ceramic
   c. Glass
   d. Metal (tin, aluminum, steel)
   e. Plastic
   f. Styrofoam

Procedure:

1. Students will work in groups of four (each student will analyze the cooling of a different cup.
2. Students may need to check the accuracy of their thermometers by placing them in constant temperature water baths.
   a. Ice water bath at 0 °C.
   b. Boil water at Temp 99-100 °C
3. Place the same amount of water (200 ml) into each of several different kinds of cups (70-80 °C heated water) (students need a hot pad)
4. Read the temperature of the water after it equalizes.
5. Read the temperature of the water in the cup every 30 seconds for 12-15 minutes. (Make certain cups are spread apart so all cool at about the same rate).
6. Record temperature versus time and graph the results. Draw a line of best fit (best straight line).
   a. Find the slope of each graph. (This slope will be negative).
   b. The slope will indicate the cooling rate. (The negative sign means the water is cooling down).
   c. Students will need to review the concept of slope as it relates to a rate of change. (Units will be °C per minute).
7. Graph the data on the graph paper provided.
8. The graph that shows the fastest drop to the right (steepest slope) is the one that represents the fastest rate of cooling. This is

therefore the cup that loses the most heat per minute and is the poorest insulator.

Teacher Tips:

1. Students may need to use only four cups vs. the eight used in the example.
2. Provide students with graph paper or graph with Excel.
3. Review the concept of slope with students. The slope for this graph will be negative.
4. Students may need to calibrate their thermometers using an ice bath and boiling water.
5. The water is hot and the students need to use hot pads.
6. The sample data in Excel graphing is included with the Teacher Edition. You may choose to include it with your student edition if you wish.

Data:

Time	Cup 1	Cup 2	Cup 3	Cup 4
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				

23				
24				
25				

15 minutes of cooling

Calculations:

Students need to calculate the slope of each line (each individual cup). Excel will calculate the slope of the graph if you choose to use Excel.

Cup 1	Cup 2	Cup 3	Cup 4

Conclusion:

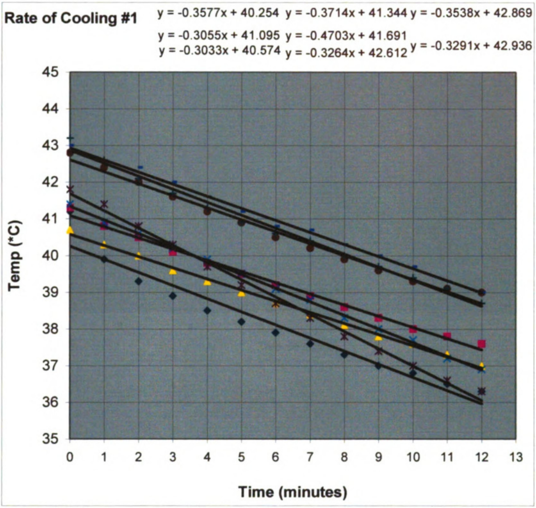
1. How accurate was your thermometer?
2. How do the cups lose heat?
3. What did the experiment attempt to accomplish?

Fact: Some insulators conduct heat so poorly that warm water insulated by their use loses only one degree (C) per year.

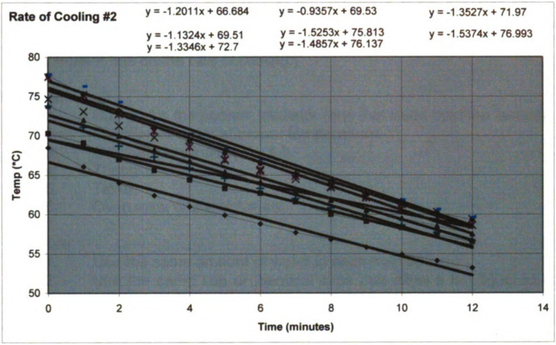
1. How close was the calibrated temperature to 0°C and 100°C when placed
in the calibrating ice water and boiling water.
2. Cups lose heat by conduction, slight convection and radiation.
3. This investigation attempts to show how temperature decreases as heat
is lost from the cup. The decrease in temperature shows the motion of
the molecules slows down as thermal energy is removed from the cup.
Additionally, this investigation illustrates that different material will lose
heat energy at different rates.
4. The two included examples show the cooling of water initially at 45 and
75°C. Students should use 80-90°C water if possible.

Lab 2 – Heat Loss (Measuring the Rate of Cooling) – Teacher's Edition

Time	Cup1	Cup2	Cup3	Cup4	Cup5	Cup6	Cup7	Cup8
0	41.2	41.3	40.7	41.4	41.8	42.8	43.2	43
1	39.9	40.8	40.3	40.9	41.4	42.4	42.6	42.5
2	39.3	40.5	40	40.6	40.8	42	42.1	42.4
3	38.9	40.1	39.6	40.2	40.3	41.6	41.7	42
4	38.5	39.8	39.3	39.9	39.7	41.2	41.3	41.6
5	38.2	39.5	39	39.5	39.2	40.9	40.9	41.2
6	37.9	39.2	38.7	39.1	38.7	40.5	40.6	40.8
7	37.6	38.9	38.4	38.8	38.3	40.2	40.4	40.7
8	37.3	38.6	38.1	38.3	37.8	39.9	40	40.3
9	37	38.3	37.8	38	37.4	39.6	39.7	40
10	36.8	38	37.6	37.7	37	39.3	39.4	39.7
11	36.5	37.8	37.3	37.2	36.6	39.1	39.1	39.3
12	36.3	37.6	37	36.9	36.3	39	38.7	39



Time	Cup1	Cup2	Cup3	Cup4	Cup5	Cup6	Cup7	Cup8
0	68.5	70.3	73.8	74.7	77.5	77.7	73.8	77.8
1	66.1	69.1	72	73.1	75.2	75.3	71.1	76.3
2	64	67	70	71.3	72.8	73.2	68.7	74.3
3	62.4	65.6	68.2	69.8	70.6	71.1	67.3	72.2
4	61	64.4	66.8	38.2	68.6	69.3	65.9	70.2
5	59.9	63.3	65.4	66.9	67	67.8	64.6	68.3
6	58.8	62.7	64.1	65.7	65.5	66.5	63.3	67
7	57.7	61.6	62.9	64.5	64.9	65.1	62	65.6
8	56.8	60	61.8	63.4	63.5	64	60.8	64.3
9	55.8	59.1	60.5	62.3	62.1	62.7	59.7	63
10	54.9	58.3	59.5	61.3	60.7	61.7	58.6	61.8
11	54.1	57.4	58.5	60.3	59.6	60.2	57.7	60.6
12	53.2	56.5	57.5	59.4	58.6	59.3	56.6	59.6


Rate of Cooling #2
y = -1.2011x + 66.684
y = -0.9357x + 69.53
y = -1.3527x + 71.97
y = -1.1324x + 69.51
y = -1.3346x + 72.7
y = -1.5253x + 75.813
y = -1.4857x + 76.137
y = -1.5374x + 76.993
Temp (°C)
80
75
70
65
60
55
50
0
2
4
6
8
10
12
14
Time (minutes)

Lab 3 – Heat Loss (Measuring the Rate of Cooling-Second) – Teacher's Edition

Purpose:

To determine the effect, if any, of the difference in temperature between the inside and the outside of the cup that is the poorest insulator. (We will determine the effect a difference in temperature on the two sides of a poor insulator has on the rate of cooling.)

Equipment:

1. Cup that is the poorest insulator (one that loses heat the fastest).
2. Supplies of water at proper temperatures.
3. Graduated cylinder (250 ml).
4. Thermometer.
5. Timer.
6. Oven mitts or paper towels.

Procedure:

1. Use the same amount of water in each trial (200 ml)
2. Use the same cup or identical cups that allow a hot liquid to cool rather quickly.
3. First, start with hot water (95 to 100° C)
4. Second, water at 60-65° C
5. Third, water at 35-38° C
6. Record the temperature for the three different situations as in the first rate of cooling experiment. (Record the temperature every 30 seconds).
7. Graph the data from each trial on the same piece of graph paper.

Data:

Time	95-100° C Water	60-65°	35-37°
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			

15			
16			
17			
18			
19			
20			

Calculations:

1. Graph the data on the graph paper provided and find the slope of each line. (What is the meaning of each slope)?
2.

Calculations	95-100°C	60-65°C	35-37°C
Slope			

Show sample calculations for the 95-100°C trial.

Calculations	95-100°C
Slope	

Teacher Tips:

1. Teachers need 12-15 cups that lose heat quickly (soup cans may work well)
2. Need to provide students with graph paper or access to a computer to use Excel.
3. Water is very hot so students need tongs or hot pads.
4. The hottest water 95-100°C should be measured exactly in a 250 ml beaker and poured directly into the cup.
5. The 60-65°C water can be prepared and placed in an insulated cooler with a spout.
6. The 35-37°C water can be obtained from the tap.

Lab 3 – Heat Loss (Measuring the Rate of Cooling-Second) – Teacher's Edition

Conclusion:

1. What is the meaning of the three graphs if they are all parallel?
2. What is the meaning if some of the graphs slope upward to the right?
3. What is the meaning of a graph that is parallel to the x-axis?
4. What is the meaning of three graphs that have different slopes?
5. Would you expect a large difference or a small difference in this experiment?
6. How could the graph be changed to show small differences more distinctly?
7. What conclusions did you reach? Does hot water cool faster or slower than cool water?

1. If the three graphs are all parallel it means their rate of temperature change is the same irregardless of the starting temperature.

2. If the graphs slope upward to the right, it would mean the temperature is rising and therefore heat is being gained and not lost.

3. If the graph is parallel to the x-axis, it would mean the temperature is remaining constant and no heat is being lost.

4. Three different slopes indicate that at different initial temperatures water loses thermal energy at different rates.

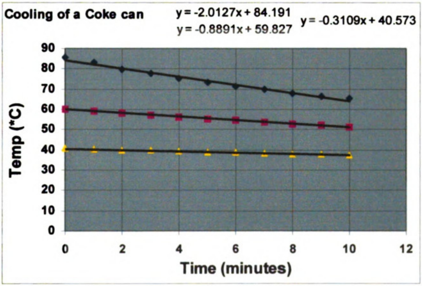
5. A small difference.

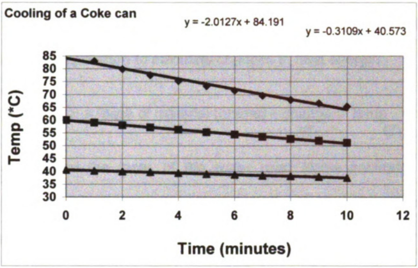
6. To show small differences in cooling rates clearly the scales on the graphs can be changed to spread out the data.

7. The results of this investigation show that hot water cools at 2°C per minute, 65° water cools at .9°C per minute while 40°water in my example cooled at .3°C per minute. The lower the starting temperature the slower the water cools.

Lab 3 – Heat Loss (Measuring the Rate of Cooling-Second) – Teacher's Edition

	Time	Hot Water	Warm Water	Cold Water
0		85.4	60	40.6
1		83	59	40.2
2		79.9	58	40
3		77.5	57.1	39.7
4		75.3	56.2	39.3
5		73.3	55.3	39
6		71.5	54.4	38.7
7		69.6	53.5	38.3
8		68	52.7	38.1
9		66.6	51.9	37.8
10		65.3	51.1	37.5




Cooling of a Coke can
y = -2.0127x + 84.191
y = -0.3109x + 40.573
Temp (*C)
85
80
75
70
65
60
55
50
45
40
35
30
0
2
4
6
8
10
12
Time (minutes)

Lab 4 – Introduction to Heat Measurement - Teacher's Edition

Purpose:

We need to be able to distinguish heat from temperature. Making this distinction allows us to use heat as a measure of energy. We need to use changes in temperature to calculate changes in heat energy.

Background:

Heat energy (Q) = Mass of material (grams) • change in temp • specific heat
ΔT C (calories C=1)

We should find the mass of the water used (more accurate) than using volume.

The starting temperature may be any value (each student may select his/her own starting temperature – makes for a good experiment). – The student makes up his/her own starting temperature somewhere between 1-8°C.

Equipment:

1. Styrofoam cups (large)
2. Thermometers – 10 to 110 °C
3. Graduated cylinders – 100 ml
4. Supply of water of known temperature (can be dipped from pan that has stood in the lab – this water was originally between 0 and 5°C and was allowed to warm to room temperature).

Procedure:

1. Find the temperature of the 1st 100 ml sample (25° C).
2. Record an imaginary starting temperature (must be above freezing) 5°C (student pick).
3. Find ΔT 25° - 5° = 20°C
4. Need mass of water placed in cup 1 (close to 100 g).
5. Add a second (100 ml) sample to the Styrofoam cup (same as first 100 g sample).
6. Find the temperature of the water in the cup after the second sample was added.
7. Find the heat energy change for the first addition
   Q = 100 g • 20°C = 2000 cal
8. Find the heat energy change for the second addition
   2000 cal
9. Find the heat energy change of the water in the cup after the second addition has been made.
   2000 + 2000 = 4000 calories

Lab 4 – Introduction to Heat Measurement - Teacher's Edition

Data:

Measurement	Cup 1	Cup2
1. Mass of cup	11.42 grams	11.37 grams
2. Mass of cup + water	111.37 grams	111.43 grams
3. Starting temperature – T_i	5°C	5°C
4. Room temperature – T_{rm}	25°C	25°C
5. Temp after 2nd addition – T_f	25°C	

Calculations:

Calculation	Cup 1	Cup2
1. ΔT for 1st addition	20°C	20°C
2. Mass of H_20 of 1st addition	99.95 grams	100.06 grams
3. Q for 1st addition	1999 calories	
4. Q for 2nd addition	2001 calories	
5. Total energy after 2nd addition	4000 calories	
6. Change in temperature from 1st to 2nd addition	25°C	

Sample calculation for cup 2

Calculations:

Calculation	
1. ΔT for 1st addition	25°C - 5°C = 20°C
2. Mass of H_20 of 1st addition	111.43 g – 11.37 g = 100.06 g
3. Q for 1st addition	99.95 g • 20°C • 1 calorie / g• °C = 1999 calories
4. Q for 2nd addition	100.06 g • 20° C • 1 calorie / g• °C = 2001 calories
5. Total energy after 2nd addition	2000 cal + 2000 cal = 4000 cal
6. Change in temperature from 1st to 2nd addition	25°C (no change in temperature)

Lab 4 – Introduction to Heat Measurement - Teacher's Edition

Conclusion:

We found that if we add more water of the same temperature we increased the heat content but did not raise the temperature. How do we explain this observation? Reflect on our class discussion and your class notes.

For the temperature of a system to change, thermal energy needs to flow from hot to cold.

Both systems are at the same temperature and as a result there is no net heat flow.

The total amount of energy remains constant.

Basically, the same amount of water (our 2 100 gram samples) at the same temperature contain the same amount of thermal energy. (The samples are equally hot or cool depending on your perspective. Therefore, there is no flow of heat when these two samples are combined.

Lab 5 – The Calorie (A Working Definition) – Teacher's Edition

Purpose:

1. To verify the working definition of the calorie (The amount of energy needed to raise 1 gram of water 1°C.)
2. To use the equation $Q = g \bullet c \bullet \Delta T$ to evaluate the data collected during the investigation.
3. To emphasize the fact that temperature is a measure of E_K (kinetic energy – energy of motion) and not a measure of heat.

Equipment:

1. 150 ml beaker
2. Hot plate (set on 3 or 4)
3. Thermometer
4. Distilled water
5. Balance
6. Clock

Procedure:

1. Need 1-150 ml beaker filled with different amounts of distilled water for each trial. (Measure water used in each trial in grams.)
2. Measure T_i for each beaker before heating.
3. Place all the beakers on the same hot plate (preset) for the same amount of time.
   (In the general sense the student should see all the beakers are exposed to the same heat sources, therefore, the same amount of energy in the same time frame.)
4. Amounts of water to be used in each trial (grams) – (one partner can do the first set while the second partner does set 2 – partners can share data)
   a. 20, 30, 40, 50, 60
   b. 20, 40, 60, 80, 100
5. Heat all the beakers for the same amount of time. (2 minutes) – The student should get a good ΔT for the beakers with the smallest amount of H_2O.
6. Measure T_f in all the beakers (at the end of 2 minutes).
   (Ask students which beaker received the greatest amount of heat energy.)
7. Use $Q = \text{grams} \bullet C \bullet \Delta T$ to calculate the heat energy transferred to the water (appearing as E_K) in each beaker.
   Do an average and calculate a percent difference with respect to the average.
   Discuss sources of error involved in doing this investigation.
8. See if you can graph the data and come up with anything meaningful.

Lab 5 – The Calorie (A Working Definition) – Teacher's Edition

Data: (20, 30, 40, 50,60 ml)

Measurements	Trial 1 (20 ml)	Trial 2 (30 ml)	Trial 3 (40 ml)	Trial 4 (50 ml)	Trial 5 (60 ml)
1. Mass of beaker	49.05 g	49.05 g	49.05 g	49.05 g	49.05 g
2. Mass beaker + water	69.22 g	79.74 g	83.30 g	99.04 g	109.21 g
3. Initial temperature T_I	27.3°C	27.8°C	27.7°C	27.0°C	24.4°C
4. Temperature final (T_f)	71.8°C	57.1°C	50.1°C	44.8°C	42.9°C
5. Time heated	2 min	2 min	2 min	2 min	2 min

Data: (20, 40, 60, 80,100 ml)

Measurements	Trial 1 (20 ml)	Trial 2 (40 ml)	Trial 3 (60 ml)	Trial 4 (80 ml)	Trial 5 (100 ml)
1. Mass of beaker					
2. Mass beaker + water					
3. Initial temperature T_I					
4. Temperature final (T_f)					
5. Time heated					

Lab 5 – The Calorie (A Working Definition) – Teacher's Edition

Calculations for 20, 30, 40, 50, 60 ml

Calculation	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
1. Mass of water	20.17 g	30.69 g	40.27 g	50.00 g	60.16 g
2. ΔT for water	44.5°C	29.3°C	22.9°C	17.8°C	15.0°C
3. Specific ht of water	1 cal/ g °C	1 cal/ g °C	1 cal/ g °C	1 cal/ g °C	1 cal/ g °C
4. Heat absorbed by each beaker	898 cal	899 cal	902 cal	890 cal	902 cal

Show a sample calculation for trial 2

Calculation	Trial 2
1. Mass of water	79.74 – 49.05 = 30.69 g
2. ΔT for water	57.1°C = 27.8 °C = 29.3°C
3. Specific heat of water	1 cal/g°C
4. Heat absorbed by the beaker	30.69 g • 29.3 °C •1 cal/g°C = 899 cal

Lab 5 – The Calorie (A Working Definition) – Teacher's Edition

Calculations for 20, 40, 60, 80, 100 ml

Calculation	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
1. Mass of water					
2. ΔT for water					
3. Specific heat of water					
4. Heat absorbed by each beaker					

Show a sample calculation for trial 4

Calculation	Trial 4
1. Mass of water	
2. ΔT for water	
3. Specific heat of water	
4. Heat absorbed by the beaker	

Conclusion:

1. Where does the energy for the hot plate come?

2. What energy changes occur in the hot plate?
3. Where does the energy from the hot plate transfer?
4. What happens to the water as energy is transferred from the hot plate?
5. Are energy (heat and electricity in our case) and temperature the same thing?
6. What overall energy conversions are occurring from the generating plant to the final results of our experiment?
7. How did you calculate the heat absorbed by the water?

1. The energy for the hot plate is electrical and comes from the chemical energy stored in the fossil fuels that are burned at the power plant.
2. At the hot plate electrical energy is transformed into heat energy.
3. The heat energy is conducted to the beaker and then to the water.
4. The water absorbs energy from the hot plate and the molecules begin to move faster (increase in kinetic energy), as a consequence of the rise in temperature.
5. Heat energy flows from the hot plate to the cold water. The consequent change in temperature tells us the molecules are moving faster. Temperature is a measure of molecular kinetic energy and not a measure of heat. However, it is used to help calculate the change in heat after the thermal energy has moved from hot to cold.
6. The energy conversions that occurred include chemical energy (fuel) is released as heat energy to create steam. The created steam turns the generators (mechanical energy) to produce electrical energy. The electrical energy goes through the power grid and in our case is changed back to heat energy.
7. $Q = \text{grams} \bullet \Delta T \bullet \text{specific heat}$

Teacher Tips:

1. Use the same 100 or 150 ml beaker for all the trials.

2. Preheat the hot plate (my setting was 3-4) and let it sit for 5-10 minutes so it is in equilibrium.
3. Students should always place the beaker on the same spot on the hot plate.
4. Students should stir their samples during the 2-minute heating period. (Be certain to read the temperature at the end of 2 minutes.
5. Be certain that you time the heating of the beakers so they are all heated the same.

Lab 6 – How to Check Up on Heat Measurement – Teacher's Edition

Purpose:

To make heat measurements that will allow the student to determine the final temperature of the system when hot and cold water are mixed together.

Background:

The energy change in any heat experiment done with proper insulation may be expressed as:

Energy gained = energy lost (1st law)

(The losses of heat energy should be small if good calorimeters are used.)

Heat is measured (calculated) using the following formula:

$$Q = \text{grams} \bullet \Delta T \bullet \text{specific heat}$$

We are going to fill 2 calorimeters with equal amounts of water (90-100 ml) at different temperatures. (We will measure the mass of the water in addition to its volume).

We can use $Q = g \bullet \Delta T \bullet C$ to predict the temperature that should result when the two samples are mixed using the concept that heat lost equals heat gained.

Students will compare the temperature predicted with the temperature actually measured after mixing.

Equipment:

1. Styrofoam cups (calorimeter).
2. Graduated cylinder
3. Thermometer
4. Balance
5. Water samples of different temperatures

Procedure:

1. Find the mass of a Styrofoam cup #1.
2. Fill the cup less than ½ full of room temperature water and find the mass of the cup and water. (add 90-100 g water).

3. Measure the volume of water that is equal to that used in part 1 – should be 10 °C lower (this water needs to be prepared in advance – mix ice and water).
   a. Need mass of cup 2.
   b. Need mass of cup 2 and cold water.
4. Need to calculate the temperature expected to be reached when cup 1 is mixed with cup 2.

Cup 1	100° g at 20 C	Method 1 – This may be a
Cup 2	<u>100° g at 10 C</u>	logical approach for most
	200° g at 15 C	students.

\- -

Heat lost = heat gained — Method 2

Grams hot • ΔT (hot) = Grams cold •ΔT(cold) (Solve this equation for T_{eq})

$(T_{hot} - T_{eq})$ $(T_{cold} - T_{eq})$

5. Record the value from the experiment.
6. Do a % error (absolute and %).
7. Do a second trial but have cup 2 warmer than room temperature.

Data:

Measurements	Part 1 (Rm temp + Colder Water) 10°C		Part 2 (Rm temp + Warmer Water) 40°C	
	Trial 1	Trial 2	Trial 1	Trial 2
Mass Cup 1	11.17 g		11.17 g	
Mass Cup 1+ Water	111.46 g		111.78 g	
T_i Cup 1	32.3°C		26.4°C	
Mass Cup 2	11.43 g		11.48 g	
Mass Cup 2 + Water	111.13 g		111.72 g	
T_i Cup 2	22.7°C		41.2°C	
T_{eq}	27.7°C		33.8°C	

Calculations:

Calculations	Part 1		Part 2	
	Trial 1	Trial 2	Trial 1	Trial 2
T_{eq} based on using an average	27.5°C		33.8°C	
T_{eq} based on heat lost = heat gained	27.6°C		33.8°C	
Absolute error	.1°C		0	
% error	.4%		0%	

Show sample calculations for part 1, trial 1 and part 2, trial 2

Calculations	Part 1 Trial 1	Part 2 Trial 2
T_{eq} based on using an average	32.3°C + 22.7°C = 55°C 55°C/2 = 27.5°C	26.4°C + 41.2°C = 67.6°C 67.6°C/2 = 33.8°C
Predicted based on heat lost = heat gained	$111.46(32.3 - T_{eq}) = 111.13(T_{eq} - 22.7)$ T_{eq} = 27.6°C	$111.79(41.2 - T_{eq}) = 111.72(T_{eq} - 26.4)$ T_{eq} = 33.8°C
Absolute error	27.7°C – 27.6°C = .1°C	38.8°C – 33.8°C = 0
% error	.1/27.6°C = .004 • 100 = .4%	0/33.8°C = 0%

Lab 6 – How to Check Up on Heat Measurement – Teacher's Edition

Extensions (for more capable students):

1. What if we used twice as much water of one temperature as water of the other temperature?
   a. Predict the equilibrium temperature.
   b. Perform the experiment, check it and calculate the error.
2. Predict the temperature when 3 equal volumes of water each at a different temperature are mixed (perform experiment).
3. Predict the temperature when 3 unequal volumes (masses) of water are mixed each at a different temperature (perform experiment).

Conclusion:

Write a type 1 response (use 1 or 2 of these to write the type 1 response):

1. In 10 lines or more write down things you know, things you think you know or questions you have about this investigation (activates prior knowledge).
2. Based on this experiment, write down three things that were interesting, two things that were confusing and one thing you would like to know more about. (Allow students to reflect.)
3. What happens when hot stuff is mixed with cooler stuff? (Allows students to make connections.)
4. When I write the test, what questions might I ask which might require a short written answer? (Allows student to think about learning.)

Teachers – you need to read and reflect on the responses your students choose to write on. Their responses will allow you to see where you need to spend more time reviewing and revising. Their responses should give you a good indication of where they are individually in this process. The next three labs are patterned after this exercise but use water at very different temperatures and in the last case in different amounts. If they are going to be successful in future labs, the basic ideas need to be in place at this point.

Lab 6 – How to Check Up on Heat Measurement – Teacher's Edition

Teacher Tips:

1. Teachers need to address the algebra involved when solving the equation for the predicted equilibrium temperature.
2. Our equation is based on the first law of thermodynamics (heat lost equals heat gained).
   grams $_{hot}$ ($T_i = T_{eq}$)= grams $_{cold}$ ($T_{eq} = T_{i\ cold}$)
   Students need to substitute their values and solve for T_{eq} (x) = This is their predicted value.
3. We use equal amounts of water so the exercise should be somewhat logical.

   100 g Hot at 20 °C — Use a simple average to calculate T_{eq}
   100 g Cold at 10°C
   30°C/2 = 15°C

4. Need to let 1-2 gallons of water sit in a container at room temperature. Set up a second container with water and ice cooling to ≅ 8-10°C.

Lab 7 – Mixing Hot Water and Cold Water – Teacher's Edition

Purpose:

To find the effect of mixing two equal volumes (or equal masses) of water at two different temperatures (Students will use very hot and very cold water).

Procedure:

Part 1

1. Find mass of calorimeter.
2. Find mass of calorimeter + addition of ≅ 100 g of cold water 5-8 °C
3. Find T_i for the cold water.
4. Repeat steps 1-3 with very warm water (80-90°C) Heat 100 ml and pour directly into calorimeter
5. Pour water together into 2nd cup, stir, and find the equilibrium temperature (pour cold water into hot water).
6. Does equilibrium agree with the predicted value?

Data – Part 1

Measurements	Trial 1	Trial 2
Mass of Cup 1	11.48 g	
Mass of Cup 1 + cold water	111.65 g	
T_i - Cup 1	5.6°C	
Mass of Cup 2	11.17 g	
Mass of Cup 2 + warm water	110.87 g	
T_i - Cup 2	84.3°C	
Teq – system	44.8°C	
Predicted value	44.9°C	

Show work to predict T_{eq}

<u>Predicted Calculation – (Heat Lost = Heat Gained)</u>

$99.70\ (84.3 - T_{eq}) = 100.17\ (T_{eq}) - 5.6)$

$8405 - 99.7\ T_{eq} = 100.17\ T_{eq} - 561$

$199.87\ T_{eq} = 8966$

$T_{eq} = 8966/199.87 = 44.9°C$

Using an Average

$84.3 + 5.6 = 89.9$

$89.9/2 = 4.85°C$

Lab

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6.Q lost)
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Lab 7 – Mixing Hot Water and Cold Water – Teacher's Edition

Calculations:

Calculations	Trial 1	Trial 2
1. Mass of cold water	100.17 g	
2. ΔT for cold water	39.2°C	
3. Q for cold water (heat gained)	3927 cal	
4. Mass of warm water	99.70 g	
5. ΔT for warm water	39.5°C	
6.Q for warm water (heat lost)	3938 cal	
7. Difference between heat lost and heat gained	11 cal	
8. % difference	.3%	
9. Difference between the predicted and measured T_{eq}	0	
10. % error in T_{eq}	0	

Teacher Tips:

1. This is basically the same format as experiment 6 but we used very hot and very cold water, which need to be prepared in advance for student use.
2. Use both methods (the average and the algebra) to predict the equilibrium temperature. (Teacher may still need to do 2-3 examples.
3. Students need to work through sample calculations with their data. Their measured equilibrium temperature should agree to within 2-3% of their predicted value.
4. Students need to be careful with the hot water. The hot and cold water can be placed in insulated dispensers for student use.

Lab 7 – Mixing Hot Water and Cold Water – Teacher's Edition

Need sample calculations here Trial 1 or Trial 2

Calculations	Trial __1___
1. Mass of cold water	111.65g – 11.48g = 100.17 g
2. ΔT for cold water	44.8°C – 5.6°C = 39.2°C
3. Q for cold water (heat gained)	100.17g • 39.2°C • 1 cal/g°C = 3927 cal
4. Mass of warm water	110.87g – 11.17g = 99.70 g
5. ΔT for warm water	84.3°C – 44.8°C = 39.5°C
6.Q for warm water (heat lost)	99.70g • 39.5°C • 1 cal/g°C = 3938 cal
7. Difference between heat lost and heat gained	3938 – 3927 = 11 cal
8. % difference	11 cal/3932.5 cal = .003 • 100 = .3%
9. Difference between the predicted and measured T_{eq}	44.8 vs. 44.8
10. % error in T_{eq}	0%

Lab 7 – Mixing Hot Water and Cold Water – Teacher's Edition

Conclusion:

1. When you think about mixing very hot and very cold water together what are some of the things you wonder about?
2. How was this type of experiment similar to another type of experiment we have already accomplished? How is it different?
3. Describe a pitfall to avoid when doing this experiment.

1. The conclusion again is open-ended to allow for teacher insight. Some of
the same problems may continue to occur and may need more
explanation. This process allows you to continue to see where your
students are and what you need specifically to do to help them with their
calculations.
2. This experiment was similar to #6, however the temperature of the hot
and cold water is very different. The technique used in the calculations
was exactly the same.
3. You may to explain the term pitfall.

Lab 8 – Mixing Hot Water and Cold Water II – Teacher's Edition

Purpose:

To find the effect of mixing unequal amounts of hot and cold water.

Procedure:

Same as previous experiment but change the amounts of hot and cold water used. (All students will select their own values).

1. Find mass of calorimeter.
2. Find mass of calorimeter 1/3 full of cold water, 5-8°C (50 to 75g)
3. Find T_i for the cold water.
4. Repeat steps 1-3 with very warm water, 90°C (100 to 125 g)
5. Pour water together into 2nd cup, stir and find the equilibrium temperature (pour cold water into hot water).
6. Does equilibrium agree with predicted value?
7. Do a second trial and reverse the amount of cold and hot water.
8. % difference = the difference between values/the average of values.

Data:

Data	Trial 1	Trial 2
1.Mass of cup 1	11.17 g	11.17 g
2. Mass of cup1 + cooler water	73.72 g	134.91 g
3. T_i – cooler water	1.9° C	8.7°C
4. Mass of cup 2	11.48 g	11.48 g
5. Mass of cup 2 + hot water	135.77 g	75.41 g
6. T_i – hot water	84.2 °C	78.4°C
7. T_{eq} - mixture	56.0°C	32.6°C

Show work for predicted value here for Trial 1 and Trial 2

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me
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Lab 8 – Mixing Hot Water and Cold Water II – Teacher's Edition

Trial 1	124.29 (84.2 – x) = 62.55 (x-1.9) 10,465 – 124.29 T_{eq} = 62.55 T_{eq} - 119 186.09 T_{eq} = $\frac{10,504}{186.04}$ T_{eq} = 56.9°C
Trial 2	123.8 (T_{eq} - 8.7) = 63.9 (78.4 - T_{eq}) 123.8 T_{eq} - 1077 = 5010 – 63.9 187.7 T_{eq} = $\frac{6087}{188.7}$ T_{eq} = 32.4°C

Calculations:

	Trial 1	Trial 2
1. Mass of water – cup 1	62.55 g	123.80 g
2. $\bar{\Delta}$ T for water – cup 1	54.1°C	23.9°C
3. Heat gained by water in cup 1	3384 cal	2959 cal
4. Mass of water – cup 2	124.29 g	63.90 g
5. ΔT for water in cup 2	28.2°C	45.8°C
6. Heat lost by water in cup 2	3505 cal	2927 cal
7. Difference	121 cal	32 cal
8. % difference	3.5%	1.1%
9. Predicted T_{eq} from initial measurements	56.9	32.4
10. % error in T_{eq}	1.6%	.6%

Lab 8 – Mixing Hot Water and Cold Water II – Teacher's Edition

Need sample calculations here Trial 1 or Trial 2

Calculations	Trial 2
1. Mass of cold water	134.91 g – 11.17 g = 123.8 g
2. ΔT for cold water	32.6°C – 8.7°C = 23.9°C
3. Q for cold water (heat gained)	123.8 g • 23.9°C • 1 cal/g°C = 2959 cal
4. Mass of warm water	75.41 g – 11.48 g = 63.9 g
5. ΔT for warm water	78.4°C – 32.6°C = 45.8°C
6.Q for warm water (heat lost)	63.9 g • 45.8°C • 1 cal/g°C = 2927 cal
7. Difference between heat lost and heat gained	2959 cal – 2927 cal = 32 cal
8. % difference	32 cal/2943 cal = .011 = 1.1%
9. Difference between the predicted and measured T_{eq}	32.4°C – 32.6°C = .2°C
10. % error	.2%°C/ 36.4°C = .006•100 = .6%

Conclusion:

1. How far was your experimental T_{eq} from ideal conditions?
2. What sources of error could have affected your final results?
3. How did the % difference compare to the % error?
4. What is the difference between a % error and a % difference?

1. Student needs to reflect on his/her data.
2. Students should reflect on their technique, this being the third
experiment following the same general procedure.
3. Reflection of student measurements.
4. Students should reflect on teacher led class discussion.

Lab 8 – Mixing Hot Water and Cold Water II – Teacher's Edition

Teacher Tips:

1. Teachers need to review the use of % difference and its calculation.
2. Often in the laboratory students have no best value for comparison when they make measurements. If the investigator has made 2 measurements of the same quantity, they may wish to calculate the % difference between those two measurements.
3. $$\% \text{ difference} = \frac{\text{(difference between values)}}{\text{average of values}}$$

Lab 9 – Mixing Hot Water and Cold Water III – Teacher's Edition

Purpose:

To re-emphasize the difference between heat energy and temperature when unequal volumes at the same temperature are mixed.

Equipment:

1. Styrofoam calorimeter
2. Thermometers
3. Balance or graduate
4. Warm water (supply of)

Procedure:

1. Combine unequal volumes of water at the same temperature.
2. Carefully measure the quantity of water with a graduate or balance.
3. Pour 30 ml of warm water into calorimeter cup 1 (more if cup is larger) . Record the temperature.
4. Pour in 60 ml or twice the first volume into the same cup. Record the temperature.
5. For Trial 2 reverse the amounts of warm and cold water.

Data:

Measurement	Trial 1	Trial 2
1. Volume 1st warm water	200 ml	100 ml
2. Volume 2nd warm water	100 ml	200 ml
3. Temp of 1st volume	31.4°C	32.6°C
4. Temp of 2nd volume	31.4°C	32.6°C
5. Temp of mixture	31.4°C	32.6°C
6. Volume of mixture	300 ml	300 ml

Teacher Tips:

Teachers, do this lab as a demonstration. This exercise reflects information from experiment 4 using different amounts of water instead of the same amounts. The general concepts covered in 4 are still pertinent to this exercise irregardless of the amounts of water used.

Lab 9 – Mixing Hot Water and Cold Water III – Teacher's Edition

Conclusion:

1. Were the temperature of the warm water put into the cup the same?
2. How does the available energy from 60 ml of water compare with the energy available from 30 ml (both at the same temperature)?
3. When we add a supply of water that has twice the energy and twice the mass why does the temperature not rise?

Referencing experiment 4 students should be able to see there is no
difference in temperatures between the water samples. Therefore, there is
no heat flow and as a result of no heat flow, no change in temperature.

Lab 10 – Calorimeter Constant – Teacher's Edition

Purpose:

To determine the calorimeter constant for a double cup Styrofoam constant pressure calorimeter.

Background:

- The calorimeter is an insulated container that can be used to study chemical and physical changes that involve changes in energy. These changes are allowed to occur inside the calorimeter and measurements of mass and changes in temperature allow the user to calculate the heat exchange that occurs.

- The use of this device is based on the first law of thermodynamics (Law of Conservation of Energy). Based on the principle that, "Energy can neither be created or destroyed but may be converted from one form to another". In our experiments the heat lost or gained in a physical or chemical change will be equal to the heat lost or gained by the solution in the calorimeter.

- Because no system is perfect, some of the energy transferred is absorbed or lost by the material that makes up the calorimeter.

- In this investigation:
  1. We will mix hot and cold water (know mass).
  2. Determine the equilibrium temperature and the change in temperature (ΔT).
  3. We will calculate the energy lost and energy gained.
  4. Relationship:

     $\Delta Q_{Hot} = \Delta Q_{cold} + \Delta Q_{calorimeter}$

     (cal. absorbs some of the heat from hot water)
  5. We will find the energy gained or lost by the calorimeter.
     a. Unit (calories/°C)
     b. Unit (Joules/°C)
     c. The calorimeter constant represents the amount of energy absorbed or lost by the calorimeter for every 1°C change in temperature.
  6. To calculate this constant we use the following formula.

     $$\text{Calorimeter constant} = \frac{\Delta Q_{hot} - \Delta Q_{cold}}{\Delta T_{hot}} = \frac{\text{calories}}{°C}$$

     We can do this trial, determine the calorimeter constant and use the calculated value in subsequent experiments.

Lab 10 – Calorimeter Constant – Teacher's Edition

Equipment:

1. 2 calorimeters
2. Balance
3. 10 ml graduate or 10 ml syringe
4. Cold tap water
5. Warm tap water
6. 2 thermometers
7. Paper towel

Procedure:

1. Label calorimeters (cold water – warm water)
2. Find the mass of each calorimeter.
3. Add 60 ml of (7-10°C) cold water to proper calorimeter.
4. Add 60 ml of (40-45°C) hot water to proper calorimeter.
5. Find the mass of each calorimeter and its water.
6. Measure the temperature of each sample of water.
7. Pour the cold water into the warm water and record the equilibrium temperature (T_{eq})
8. Repeat the experiment to verify the results.

Data:

Measurements	Trial 1	Trial 2	Trial 3
1.Mass of cold water calorimeter	11.39 g	11.38 g	11.38 g
2. Mass of cal + cold water	142.10 g	152.98 g	151.49 g
3. T_i cold water	5.1°C	5.7°C	1.2°C
4. Mass of warm water calorimeter	11.38 g	11.37 g	11.37 g
5. Mass of cal. + warm water	143.20 g	150.17 g	154.33 g
6. T_i warm water	43.7°C	42.8°C	42.2°C
7. Final temp after mixing T_{eq}	23.9°C	23.8°C	21.2°C

Calculations:

Calculations	Trial 1	Trial 2	Trial 3
1. Mass of cold water	130.71 g	141.60 g	140.11 g
2. Cold water ΔT	18.8°C	18.1°C	20.0°C
3. Mass of warm water	131.82 g	138.8 g	142.96 g
4. Warm water ΔT	19.8°C	19.0°C	21.0°C
5. Energy gained (Q) by the cold water	2457 cal	2563 cal	2802 cal
6. Energy lost (Q) by the warm water	2610 cal	2637 cal	3002 cal
7. Absolute difference $\|\Delta Q_{warm} - \Delta Q\|_{cold})$	152.6 cal	74 cal	200 cal
8. Calorimeter constant	7.71 cal/°C	3.9 cal/°C	9.5 cal/°C
9. Average calorimeter constant	7.0 cal/°C		

Sample calculations for trial 2 (next page)

Calculations:

Calculations	Trial 2
1. Mass of cold water	152.98 – 11.38 = 141.60 g
2. Cold water ΔT	23.8 – 5.7 = 18.1°C
3. Mass of warm water	150.17 – 11.37 = 138.80 g
4. Warm water ΔT	42.8 – 23.8 = 19.0°C
5. (Q) Energy gained by the cold water	141.60 g • 18.1°C • 1 cal/g°C = 2565 cal
6. (Q) Energy lost by the warm water	138.80 g • 19.0°C • 1 cal/g°C = 2637 cal
7. Absolute difference $\|\Delta Q_{warm} - \Delta Q\|_{cold})$	(2637 cal – 2563 cal) = 74 cal
8. Calorimeter constant	74 cal/19 = 3.9 cal/°C
9. Average calorimeter constant	7.7 + 3.9 + 9.5 = 21.1/3 = 7.0 cal/°C

Lab 10 – Calorimeter Constant – Teacher's Edition

Conclusion:

1. Why did we do this investigation?
2. How did constants compare lab station to lab station?
3. When will we use this calculated value?

1. Students should be able to measure how much heat energy can be
gained or lost by the Styrofoam cup during the heat exchange process
that occurs within the cup.
2. Students need to chart the class values and arrive at a class average that
can be used by all students in future experiments. (Each calorimeter is
unique but the majority will be close to the class average.
3. Students need to use this calorimeter constant to make certain their heat
exchange bookkeeping is more accurate in future experiments.

Teacher Tips:

1. Values for the calorimeter constant may differ significantly. We will use the average of three trials.
2. Styrofoam cups have a fairly significant value for the calorimeter constant, sometimes 5-10 calories per °C.
3. Completely dry the calorimeter between trials.
4. Use Styrofoam cups separated by rubber bands (called a nested cup).
5. This gives an additional air space for more insulation.
6. Use a digital thermometer if possible.
7. Calorimeters do not need to be covered as equilibrium occurs quickly.

Lab 11 – The Mechanical Equivalent of Heat – Teacher's Edition

Purpose:

To determine the mechanical equivalent of heat (1 calorie = 4.187 Joules)

History:

Benjamin Thompson (Count Rumford) 1753 to 1814

- At this point scientists (natural philosophers) believed mechanical energy and heat were two different things.
- Thompson was hired by the Elector of Bavaria to make cannons. From Thompson's perspective the work put into turning the drill seemed to disappear rather than becoming stored as E_p or E_k. The drill and the cannon got hot with no apparent source of heat.
- Thompson suggested that the work done on the cannon (force applied over a distance) was the source of the heat. The mechanical work was changed into heat energy through the process of friction. Therefore, heat was not separate (work was converted to heat energy).

James P. Joule (1818 to 1889 – Does the quantitative work to establish the relationship between work and heat.

- With some unique apparatus he was able to transform a known amount of work into a measurable quantity of heat.
- Joule showed:
    - Heat was a form of energy
    - Calories and Joules were different sized units of the same thing and could be converted (1 calorie = 4.187 Joules)
    - His investigations determined the mechanical equivalent of heat. His devices did a know amount of work against friction and in the process measured the amount of heat produced.

Background – Theory:

In our device two surfaces slide over one another (nylon rope over copper drum)

1. A force of friction (F_f) arises parallel to the surface.
2. The F_f must be opposed by an equal parallel-applied f force if motion at a constant speed (angular) is to be maintained.
3. The applied force does work equal to the magnitude of the weight lifted times the distance through which that force moves in pushing one surface over the other.
4. The work done is not stored as E_p and does not appear as an increase in E_K of the moving body.
5. The sliding surfaces get hot (friction) and this friction transforms mechanical work into heat (a different form of energy).

6. Joule collected evidence that the amount of heat that appears is proportional to the work done against friction.
7. This experiment will allow the student to do work to lift the 5 Kg mass, which will translate into friction that heats the system and therefore allows us to measure the heat produced.
8. Our device – For demo purposes
   a. A nylon rope (cord) wrapped around a Cu calorimeter with a 5.0 kg mass hanging from the other end.
   b. A hand crank turns the drum and the user attempts to hoist the 5.0 kg mass. (However, the nylon rope slips on the drum but there is enough friction to suspend the 5.0 kg mass off the floor.)
   c. The friction between the rope and the drum produced by the work being done to try to lift the 5.0 mg mass is converted to heat energy, which raises the temperature of the cu calorimeter and the water inside.
   d. The 5.0 kg mass (49.85 N) $F_{(w)}$ = mg is the force that is overcome by the crank and is equal to the force of friction.
   e. The distance through which this force acts is equal to the distance moved by any point on the drum.
      i. D = π •d • rev.
      ii. Work = mg x distance (force = weight = mg)
      iii. Work = (mg) (π d rev)
   f. The Cu calorimeter (drum) is insulated from the base by a plastic holder.
      i. The nylon cord is in thermal contact (frictional contact) with the drug.
      ii. The Cu calorimeter is filled with water.
      iii. A thermometer is inserted into the calorimeter to monitor the temperature of the water and Cu.
   g. The heat produced by the frictional work is transferred to the water and Cu. Using Q = g• c• Δ T we can calculate the heat produced from this frictional work.
   h. When measurements are taken and calculations of work done and heat produced are completed, find the ratio

$$\frac{\text{Heat produced } (H_20 \text{ and Cu})}{\text{Work done}} =$$

Lab 11 – The Mechanical Equivalent of Heat – Teacher's Edition

Procedure:

1. Label the diagram of the apparatus (find a diagram of the apparatus in the Sargent-Welch catalog.
2. Find the mass of the calorimeter and sealing ferule.
3. Fill the calorimeter with distilled water and find the mass.
4. Use a Vernier caliper to find the diameter of the Cu calorimeter.
5. Insert the thermometer through the seal into the drum and tighten the sealing ferule.
6. Set up the apparatus.
   a. Anchor the device to the corner of a table (right front)
   b. Attach the 5.0 kg mass to the end of the nylon rope.
   c. Have the calorimeter and water 3.0° C ≅ below room temperature.
   d. Measure the initial temperature of the water and calorimeter.
   e. Crank the handle 50 turns at a time (the 5.0 kg will lift off the floor) and record the rise in temperature every 50 turns).

Data:

Measurements	Trial 1	Trial 2
1.Mass of calorimeter	104.36 g	
2. Mass of calorimeter plus water	174.00 g	
3. Initial temperature of room (T_I)	27.0°C	
4. Initial temperature of water + Copper calorimeter	22.8°C	
5. Temperature after 50 turns	23.8°C	
6. Temperature after 100 turns	24.8°C	
7. Temperature after 150 turns	25.6°C	
8. Temperature after 200 turns	27.0°C	
9. Temperature after 250 turns	28.2°C	

Calculations:

1. Calculate the work done on the 5.0 kg mass in the attempt to lift it some distance (250 turns)

Calculation	Trial 1	Trial 2
1. Distance lifted	36.58 m	
2. Weight lifted	49.85 N	
3. Force of friction	49.85 N	
4. Work done	1794.2 J	

Do the sample calculations for trial 1.

Sample Calculations:

Lab 11 – The Mechanical Equivalent of Heat – Teacher's Edition

Calculation	Trial 1
1. Distance lifted	4.66cm•3.14•250 = 3658 cm = 36.58 m
2. Weight lifted	5 kg•9.81 m/sec^2 = 49.85 N
3. Force of friction	5 kg•9.81 m/sec^2 = 49.85 N
4. Work done	49.85 N • 36.58 m = 1794.2 N•m = 1794.2 J

2. Calculate the heat energy that was produced by the frictional work and absorbed by the copper calorimeter and water.

Calculation	Trial 1	Trial 2
1. Heat absorbed by cooper calorimeter	52.1 cal	
2. Heat absorbed by water	376.1 cal	
3. Total heat absorbed	428.2 cal	

Show a sample calculation for trial 1

Calculation	Trial 1
1. Heat absorbed by cooper calorimeter	104.36 g • 5.4°C•.0924 cal/g°C=52.1 cal
2. Heat absorbed by water	69.64 g • 5.4°C•1 cal/g°C=376.1 cal
3. Total heat absorbed	52.1 cal + 376.1 cal = 428.2 cal

3. Calculate the ratio:

Calculation	Trial 1
1. Work done/heat absorbed	1794 J/ 428.2 cal = 4.19 J/cal

Lab 11 – The Mechanical Equivalent of Heat – Teacher's Edition

Conclusion:

In 10-15 lines or more write the things you know, things you think you know and questions you have about the mechanical equivalent of heat.

Lab 12 – Mechanical Equivalent of Heat (Second Technique) – Teacher's Edition

Purpose:

The student should be able to make an approximately measurement of the mechanical equivalent of heat.

Background:

English Physicist James Prescott Joule measured the relationship between mechanical energy and heat energy in a series of experiments that extended over a period of 30 years.

This experiment uses simple materials to determine the relationship between work (mechanical energy) and heat. In this experiment a measure of mass of buckshot will be placed inside a cardboard tube dropped from one end to the other with a measurement of the resultant increase in temperature. When the buckshot falls the length of the tube the work done to lift the shot (E_p) is converted to the energy of motion E_k that is then converted to heat energy through friction. Because of the insulating properties of cork and cardboard the heat energy is confined mostly to the buckshot and as a consequence its temperature will go up.

Equipment:

1. Heavy cardboard tube, 1.0 m long and 4.0 cm in diameter.
2. 2 cork stoppers – large.
3. 1.0 kg buckshot.
4. Styrofoam cup and lid.
5. Large metal pan.
6. Ice cubes.
7. Thermometer.
8. Meter stick.
9. Platform balance.

Procedure:

1. Measure the mass of the buckshot.
   a. Place buckshot in metal pan.
   b. Cool to 21-23°C by placing the pan on ice cubes (cool for about 1 minute).
   c. Need to keep buckshot dry during entire experiment (cooling may cause water to condense on the shot).
2. Pour buckshot into a Styrofoam cup.
   a. Measure temperature of buckshot 3 times.
   b. Shake buckshot between readings.
   c. Take average of 3 readings.
3. Close one end of the tube with a cork stopper and pour the buckshot into the other end (close other end with 2^{nd} stopper).
   a. Invert the tube 100 times or more in quick succession.
   b. Do not raise or lower the tube as it is inverted.
   c. Invert the tube fast enough so the buckshot falls the entire length of the tube.
   d. With each inversion the end of the tube should rest on the floor or the top of the lab table as the buckshot hits the bottom of the tube.
4. After the final inversion of the tube:
   a. Pour buckshot back into the Styrofoam cup.
   b. Measure the temperature 3 times (shake between readings).
   c. Record the average.
5. We need the average distance the buckshot falls.
   a. Pour it back into the tube.
   b. Measure from top of buckshot to the bottom of the cork stopper that is placed in the other end.
6. Do 2 more trials and record all data (use different buckshot for each trial).

Lab 12 – Mechanical Equivalent of Heat (Second Technique) – Teacher's Edition

Data:

	Trial 1	Trial 2	Trial 3
Mass of buckshot	1000g	653g	653g
Average distance of single fall	1.20 m	1.24 m	1.24m
Number of falls	100	100	100
Average initial temperature	21.0°C	21.7°C	23.8°C
Average final temperature	30.0°C	31.0°C	32.2°C

Calculations:

	Trial 1	Trial 2	Trial 3
Total potential energy of buckshot	1177 j	794 j	794 j
Temperature change	9.0°C	10.3°C	9.4°C
Specific heat of buckshot	.0305Cal/g°C	.0305Cal/g°C	.0305Cal/g°C
Calories gained by buckshot	274.5 cal	205.1 cal	198.7 cal
Mechanical equivalent of heat, experimental	4.29 J/cal	3.87J/cal	4.00 J/cal
Mechanical equivalent of heat, accepted value	4.18J/cal	4.18 J/cal	4.18 J/cal
% error	2.6%	7.3%	4.3%

Lab 12 – Mechanical Equivalent of Heat (Second Technique) – Teacher's Edition

CALCULATIONS

Show the calculations for Trial 1 in the spaces provided below. Enter the results of the calculations for all trials in the calculations table.

Calculations:

	Trial 1
Total potential energy of buckshot	W = mgh = 1.0 kg •9.81 m/sec^2• 1.2 m•100 = 1177 j
Temperature change	30.0°C – 21.0°C = 9°C
Specific heat of buckshot	.0305Cal/g°C
Calories gained by buckshot	1000 g • 9.0°C • .0305Cal/g°C = 274.5 cal
Mechanical equivalent of heat, experimental	1177 j/274.5 cal = 4.29 j/cal
Mechanical equivalent of heat, accepted value	4.18 j/cal
% error	.11 j/cal/4.18 j/cal = .026 • 100 = 2.6%

Lab 12 – Mechanical Equivalent of Heat (Second Technique) – Teacher's Edition

Conclusion:

1. Write down two things you found interesting about this investigation.
2. What were two or more things you found a bit confusing?
3. What part of this experiment would be difficult to explain to someone else? Why?
4. Based on answers to 1, 2 and 3, what things do you know, what do you think you know and what questions do you have?

This type of conclusion is harder to grade, however it will hopefully give the teacher more insight with respect to their students' understanding of the mechanical process. Read and catalog their responses and possibly do a second demonstration that addresses their concerns. (Teachers could make a list of student perception problems on the board immediately after the demo and address those problems with a second or possibly third trial. Have the students do the physical work involving the inversion of the tube. This process should make next year's presentation much easier for the teacher.

Lab 12 – Mechanical Equivalent of Heat (Second Technique) – Teacher's Edition

Purpose:

The student should be able to make an approximately measurement of the mechanical equivalent of heat.

Background:

English Physicist James Prescott Joule measured the relationship between mechanical energy and heat energy in a series of experiments that extended over a period of 30 years.

This experiment uses simple materials to determine the relationship between work (mechanical energy) and heat. In this experiment a measure of mass of buckshot will be placed inside a cardboard tube dropped from one end to the other with a measurement of the resultant increase in temperature. When the buckshot falls the length of the tube the work done to lift the shot (E_p) is converted to the energy of motion E_k that is then converted to heat energy through friction. Because of the insulating properties of cork and cardboard the heat energy is confined mostly to the buckshot and as a consequence its temperature will go up.

Equipment:

1. Heavy cardboard tube, 1.0 m long and 4.0 cm in diameter.
2. 2 cork stoppers – large.
3. 1.0 kg buckshot.
4. Styrofoam cup and lid.
5. Large metal pan.
6. Ice cubes.
7. Thermometer.
8. Meter stick.
9. Platform balance.

Lab 12 – Mechanical Equivalent of Heat (Second Technique) – Teacher's Edition

Procedure:

1. Measure the mass of the buckshot.
   a. Place buckshot in metal pan.
   b. Cool to 21-23°C by placing the pan on ice cubes (cool for about 1 minute).
   c. Need to keep buckshot dry during entire experiment (cooling may cause water to condense on the shot).
2. Pour buckshot into a Styrofoam cup.
   a. Measure temperature of buckshot 3 times.
   b. Shake buckshot between readings.
   c. Take average of 3 readings.
3. Close one end of the tube with a cork stopper and pour the buckshot into the other end (close other end with 2nd stopper).
   a. Invert the tube 100 times or more in quick succession.
   b. Do not raise or lower the tube as it is inverted.
   c. Invert the tube fast enough so the buckshot falls the entire length of the tube.
   d. With each inversion the end of the tube should rest on the floor or the top of the lab table as the buckshot hits the bottom of the tube.
4. After the final inversion of the tube:
   a. Pour buckshot back into the Styrofoam cup.
   b. Measure the temperature 3 times (shake between readings).
   c. Record the average.
5. We need the average distance the buckshot falls.
   a. Pour it back into the tube.
   b. Measure from top of buckshot to the bottom of the cork stopper that is placed in the other end.
6. Do 2 more trials and record all data (use different buckshot for each trial).

Lab 12 – Mechanical Equivalent of Heat (Second Technique) – Teacher's Edition

Data:

	Trial 1	Trial 2	Trial 3
Mass of buckshot	1000g	653g	653g
Average distance of single fall	1.20 m	1.24 m	1.24m
Number of falls	100	100	100
Average initial temperature	21.0°C	21.7°C	23.8°C
Average final temperature	30.0°C	31.0°C	32.2°C

Calculations:

	Trial 1	Trial 2	Trial 3
Total potential energy of buckshot	1177 j	794 j	794 j
Temperature change	9.0°C	10.3°C	9.4°C
Specific heat of buckshot	.0305Cal/g°C	.0305Cal/g°C	.0305Cal/g°C
Calories gained by buckshot	274.5 cal	205.1 cal	198.7 cal
Mechanical equivalent of heat, experimental	4.29 J/cal	3.87J/cal	4.00 J/cal
Mechanical equivalent of heat, accepted value	4.18J/cal	4.18 J/cal	4.18 J/cal
% error	2.6%	7.3%	4.3%

Lab 12 – Mechanical Equivalent of Heat (Second Technique) – Teacher's Edition

CALCULATIONS

Show the calculations for Trial 1 in the spaces provided below. Enter the results of the calculations for all trials in the calculations table.

Calculations:

	Trial 1
Total potential energy of buckshot	W = mgh = 1.0 kg •9.81 m/sec^2• 1.2 m•100 = 1177 j
Temperature change	30.0°C – 21.0°C = 9°C
Specific heat of buckshot	.0305Cal/g°C
Calories gained by buckshot	1000 g • 9.0°C • .0305Cal/g°C = 274.5 cal
Mechanical equivalent of heat, experimental	1177 j/274.5 cal = 4.29 j/cal
Mechanical equivalent of heat, accepted value	4.18 j/cal
% error	.11 j/cal/4.18 j/cal = .026 • 100 = 2.6%

Lab 12 – Mechanical Equivalent of Heat (Second Technique) – Teacher's Edition

Conclusion:

1. Write down two things you found interesting about this investigation.
2. What were two or more things you found a bit confusing?
3. What part of this experiment would be difficult to explain to someone else? Why?
4. Based on answers to 1, 2 and 3, what things do you know, what do you think you know and what questions do you have?

This type of conclusion is harder to grade, however it will hopefully give the teacher more insight with respect to their students' understanding of the mechanical process. Read and catalog their responses and possibly do a second demonstration that addresses their concerns. (Teachers could make a list of student perception problems on the board immediately after the demo and address those problems with a second or possibly third trial. Have the students do the physical work involving the inversion of the tube. This process should make next year's presentation much easier for the teacher.

Lab 13 – Specific Heat of a Metal – Teacher's Edition

Purpose:

To experimentally determine the specific heat of copper and aluminum and then use the procedure to determine the specific heat of an unknown metal and identify the metal from this value.

Background:

- Specific heat c is defined as the amount of heat energy (Joules or calories) needed to raise 1 gram of a substance 1°C. This value is a characteristic property of a substance and if carefully measured can be used to identify that substance.
- In this investigation:
  1. Various metals will be heated to between 95 and 98°C using steam.
  2. These metals will then be placed in a prepared calorimeter where the metal will lose its energy to the water and calorimeter.
  3. Using the method of mixtures, students will base calculations on heat lost (by the metal), will equal heat gained by the water and calorimeter.
  4. With careful measuring and attention to detail, students will be able to calculate the specific heat of the metal.

$$Q = g \bullet \Delta T \bullet c \text{ (specific heat)}$$

Procedure: (Using the steam boiler) – Make up diagrams from class demo.

1. Find the mass of the metal used.
2. Measure the T_i of the metal – (after it has been heated).
3. Measure the mass of the calorimeter cup (use Styrofoam or aluminum).
4. Measure the mass of the calorimeter cup and water (1/2 to 2/3s full of water).
5. Find the initial temperature of the water.
6. Find the equilibrium temperature after the hot metal is poured into the water and the system is allowed to come to a steady state.
7. Calculate the heat gained by the water.
8. Calculate the heat gained by the calorimeter.
9. Write an equation for the heat lost by the metal.
10. Heat gained by the water + heat gained by calorimeter = heat lost by cooling metal.

Lab 13 – Specific Heat of a Metal – Teacher's Edition

Data:

Measurement	Al	Cu	X
1.Mass of heating cup		22.54 g	
2. Mass of cup + metal		153.50 g	
3. T_i – metal (after it is heated)		94.6°C	
4. Mass of calorimeter cup		11.46 g	
5. Mass of calorimeter cup + water		125.72 g	
6. T_i – $H_2 0$ in calorimeter		25.1°C	
7. T_{eq} – Cup, $H_2 0$ and metal		31.9°C	

Calculations:

	Cu
1. Mass of metal	130.96 g
2. ΔT – metal ($T_i - T_{eq}$)	62.7°C
3.Equation for heat lost by the metal	130.96 g • 62.7°C • c = 8211 g • °C • c
4. Mass of $H_2 0$	114.26 g
5. ΔT for $H_2 0$	6.8°C
6. Heat gained by $H_2 0$– (Q = g •ΔT •c)	114.26 g • 6.8°C • 1 cal/g °C = 777 cal
7. ΔT for cal. Cup ($T_{eq} - T_i$)	6.8 °C
8. Heat gained by cal. Cup (cal constant • ΔT)	47.6 cal
9. Total heat gained	824.6 cal
10.Solve for c for the metal.	.1004 cal/g °C
11. % error	6.2%

$$\%error = \frac{|KV = EV|}{KV} \bullet 100$$

Do sample calculations for copper on next page.

Calculations:

	Cu
1. Mass of metal	153.50 g – 22.54 g = 130.96 g
2. ΔT – metal ($T_i - T_{eq}$)	94.6°C – 31.9°C = 62.7 °C
3.Equation for heat lost by the metal	130.96 g • 62.7 °C • c = 8211 g • °C • c
4. Mass of $H_2 0$	125.72 g – 11.46 g = 114.26 g
5. ΔT for $H_2 0$	31.9°C – 25.1°C = 6.8°C
6.Heat gained by $H_2 0$– (Q = g •ΔT •c)	114.26 g • 6.8°C • 1 cal/g • °C = 777 cal
7. ΔT for cal. Cup ($T_{eq} - T_i$)	31.9°C – 25.1°C = 6.8°C
8. Heat gained by cal. Cup (cal constant • ΔT)	7 cal/°C • 6.8 °C = 47.6 cal
9. Total heat gained	777 cal + 47.6 cal = 824.6 cal
10.Solve for c for the metal.	8211 c = 824.6 cal c = 824.6 cal/8211 = .1004 cal/g°C
11. % error	.1004 - .0946/.0946 = .062 • 100 = 6.2%

Lab 13 – Specific Heat of a Metal – Teacher's Edition

Conclusion:

1. What happens to the thermal energy of the metal when it is placed in the water and calorimeter?
2. What do we assume occurs during the process discussed in question 1?
3. How much energy was lost by the metal?
4. How much energy was gained by the water and calorimeter?
5. How does the calculated c compare to the known value?
6. Are there any possible sources of error in this process?

1. The thermal energy from a metal is lost to the water and calorimeter. The system adjusts to an equilibrium temperature.

2. Heat lost by the metal equals the heat gained by the water and calorimeter.

3. 8211 • c calories.

4. 824.6 cal

5. .1004 to .0924 6.2% error

6. Error sources – lag time transferring to metal. Not enough water in calorimeter to cover metal. Need to wait for equilibrium temperature. Calorimeter constant may be too high. Your class average may be less than 7 cal/°C and anything else that comes to mind.

Lab 14 – Specific Heat of a Metal (II) – Teacher's Edition

Purpose:

1. In this experiment we will use a procedure similar to the first experiment to measure c for 5 different metals.
2. Using a streamlined process, students will measure c for Cu, Zn, Fe, Al and Sn and compare their calculations with the known value.

Background:

- Specific heat c is defined as the amount of heat energy (Joules or calories) needed to raise 1 gram of a substance 1°C. This value is a characteristic property of a substance and if carefully measured can be used to identify that substance.
- In this investigation:
  1. Various metals will be heated to between 95 and 98°C using hot water.
  2. These metals will then be placed in a prepared calorimeter where the metal will lose its energy to the water and calorimeter.
  3. Using the method of mixtures, students will base calculations on heat lost (by the metal), will equal heat gained by the water and calorimeter.
  4. With careful measuring and attention to detail, students will be able to calculate the specific heat of the metal.

$$Q = g \bullet \Delta T \bullet c \text{ (specific heat)}$$

Procedure:

1. Find the mass of the individual samples of metal.
2. Heat the metal samples in a 400 ml tall beaker until they are at the temperature of the boiling water (97-99°C).
3. Prepare 5 calorimeters each with enough water to cover the metal samples when they are placed in the calorimeter. (Aluminum will present the most problem – may need to use a larger calorimeter.)
4. Assume all the metal samples are at the temperature of the boiling water before they are placed in the calorimeter.
5. Measure the initial temperature of the water in each calorimeter just before the metal is added.
6. Add the hot metal (97-99°C) to the prepared calorimeter. Allow the system to reach thermal equilibrium and record the equilibrium temperature for each of the five systems (T_{eq}).
7. Calculate the heat gained by the water.
8. Calculate the heat gained by the calorimeter.

9. Write an equation for the heat lost by each metal that contains the unknown specific heat (c).
10. Using heat lost = heat gained, solve for the specific heat of each metal.

Data (Specific Heat of Five Samples):

Metal Used	Al	Cu	Zn	Sn	Fe
Measurement	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
1. Mass of metal	31.97 g	32.08 g	31.98 g	31.91 g	32.05 g
2. T_i – metal (temperature of boiling water)	99.0°C	99.0°C	99.0°C	99.2°C	99.5°C
3. Mass of calorimeter cup	11.25 g	11.47 g	11.39 g	10.88 g	11.10 g
4. Mass of calorimeter cup + H_2 0	151.90 g	70.32 g	83.11 g	69.44 g	89.20 g
5. T_i - H_2 0	24.8°C	24.7°C	24.7°C	24.7°C	24.7°C
6. T_{eq} - H_2 0 and metal	27.9°C	28.3°C	27.6°C	26.8°C	28.2°C

Lab 14 – Specific Heat of a Metal (II) – Teacher's Edition

Calculations (Processing the Data):

Metal Used	Al	Cu	Zn	Sn	Fe
Calculations	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
1. ΔT for the metal	71.1°C	70.7°C	71.4°C	72.4°C	71.0°C
2. Heat lost by the metal (will contain unknown)	2273 c	2268 c	2283 c	2310 c	2276 c
3. ΔT - H_2 0 and calorimeter	3.1°C	3.6°C	2.9°C	2.1°C	3.5°C
4. Mass of H_2 0	140.65 g	58.85 g	71.72 g	58.56 g	78.10 g
5. Heat gained by the water.	492 cal	212 cal	208 cal	123 cal	273 cal
6. Heat gained by calorimeter	16 cal	19 cal	15 cal	11 cal	18 cal
7. Specific heat of metal	.223 cal/g • °C	.1019 cal/g • °C	.0977 cal/g • °C	.0580 cal/g • °C	.1279 cal/g • °C
8. Known value	.214 cal/g • °C	.0924 cal/g • °C	.0922 cal/g • °C	.0543 cal/g • °C	.0175 cal/g • °C
9. % error	4.2%	10.3%	6%	6.8%	19%

Lab 14 – Specific Heat of a Metal (II) – Teacher's Edition

Calculations (Processing the Data):

Calculations	Calculations for Cu
1. ΔT for the metal	99.0°C – 28.3°C = 70.7°C
2. Heat lost by the metal (will contain unknown)	32.08 g • 70.7 °C = 2268 g • °C • c
3. ΔT - $H_2 0$ and calorimeter	28.3°C – 24.7°C = 3.6°C
4. Mass of $H_2 0$	70.32 g – 11.47 g = 58.85 g
5. Heat gained by the water.	58.85 g • 3.6°C • 1 cal/g • °C = 212 cal
6. Heat gained by calorimeter	5.2 cal/°C • 3.6°C = 19 cal
7. Specific heat of metal	212 cal + 19 cal = 231 cal/2268 g • °C • c = .1019 cal/g •°C
8. Known value	.0924 cal/g • °C
9. % error	.1019 - .0924 = .0095/.0924 = .103 • 100 = 10.3%

Lab 14 – Specific Heat of a Metal (II) – Teacher's Edition

Conclusion:

1. What happens to the thermal energy of the metal when it is placed in the water and calorimeter?
2. What do we assume occurs during the process discussed in question 1?
3. How much energy was lost by the metal?
4. How much energy was gained by the water and calorimeter?
5. How does the calculated c (specific heat) compare to the known value?
6. Are there any possible sources of error in this process?

Refer to experiment 13, basically the same questions.

Lab 15 – Temperature of a Hot Body – Teacher's Edition

Purpose:

To use the principles of heat exchange to determine the initial temperature of a red-hot piece of metal.
(The energy present in the red-hot metal will be absorbed by the water in a prepared calorimeter as well as by the calorimeter).

Procedure:

1. Set up a steam boiler to be used as a holder for the piece of metal to be heated.
2. Using a coat hanger, prepare a piece of wire that will suspend the iron sample in a gas burner flame.
3. While the metal is being heated, prepare a metal calorimeter (Al) that is 2/3s full of 5.0°C water.
4. When the metal is red-hot (turn off room lights), dump the sample into the prepared calorimeter. (There will be some bumping.)
5. Allow the system to reach thermal equilibrium and reach the equilibrium temperature (T_{eq}).
6. Calculate the energy absorbed by the water.
7. Calculate the energy absorbed by the calorimeter (Al).
8. Write an equation that addresses the heat lost by the iron sample that includes ΔT as X for the unknown term.
9. Using heat lost = heat gained solve the expression for the ΔT for the iron sample.
10. Add $\Delta T + T_{eq}$ and find the T_i for the red-hot metal. Convert the temperature to:

    $F = (9/5C) + 32$

Lab 15 – Temperature of a Hot Body – Teacher's Edition

Data:

Measurements	Trial 1	Trial 2
1. Mass of the Fe sample	104.87 g	
2. Specific heat of Fe	.1075 cal/g °C	
3. Mass of cal. Cup (Al)	39.04 g	
4. Mass of cal. Cup + H_20.	240.82 g	
5. T_i of H_20	5.8 °C	
6. T_{eq} of system (metal, H_20 and cal cup)	56.2 °C	

Calculations:

Calculations	Trial 1	Trial 2
1. Mass of H_20	201.78 g	
2. ΔT for H_20 + cal cup	50.4 °C	
3. Heat gained by H_20	10170 cal	
4. Heat gained by cal cup	421 cal	
5. Total heat gained by system	10591 cal	
6. Expression for heat lost by metal	104.87 g • .1075 cal/ g°C •ΔT = 11.27 ΔT	
7. ΔT for hot metal sample	940 °C	
8. T_I for hot-body T_{eq} + $\Delta T = T_I$	996°C	
9. T_I for hot body in °F	1825 °F	

Lab 15 – Temperature of a Hot Body – Teacher's Edition

Do the sample calculations for trial of your choice.

Calculations:

Calculations	Trial 1
1. Mass of H_20	240.82 g – 39.04 g = 201.78 g
2. ΔT for H_20 + cal cup	56.2 °C – 5.8°C = 50.4°C
3. Heat gained by H_20	201.78 g • 50.4°C • 1 cal/g°C = 10170 cal
4. Heat gained by Al cal cup	39.04 g • 50.4°C • 2.14 cal/g°C = 421 cal
5. Total heat gained by system	10170 cal + 421 cal = 10591 cal
6. Expression for heat lost by metal	104.87 g • .1075 cal/g°C •ΔT = 11.27 • ΔT
7. ΔT for hot metal sample	11.27 • ΔT = 10591 cal ΔT= 10591 cal/11.27 cal/°C = 940 °C
8. T_i for hot-body T_{eq} + ΔT = T_i	940 °C + 56.2°C = 996.2°C
9. T_i for hot body in °F	(9/5 • 996.2) + 32 = 1825 °F

Conclusion:

Make up some Type 2 questions (Check the Collins' manual).

Lab 16 – Phase Changes (Freezing and Melting) – Teacher's Edition

Purpose:

1. To qualitatively analyze what happens to water when it freezes to form ice.
2. Additionally observe what happens when ice that formed is melted to reform the water.
3. Repeat the experiment and quantitatively analyze what happens to the water when it is frozen and when it is allowed to return to its liquid state.

Equipment:

1. 250 ml beaker
2. 20 X 150 test tube
3. Thermometer
4. Rock salt or ice melt (KCl)
5. Ice
6. Tap water

Procedure:

Part I (Qualitative) – You may want to ignore this section and do part II only

1. Place 1-2 ml of tap water in test tube. Place the test tube in a beaker that has a mixture of rock salt and ice. (Can use ice melt and water).
2. Make a list of all qualitative observations that occur while the cooling process is occurring. (What do you think is happening?)
3. Remove the test tube with the ice in it from the rock salt and ice mixture and place it in a beaker of room temperature water.
4. Make observations of what is happening while the test tube is warming.
5. After you complete the cooling and warming processes explain (using your own thoughts) what you think is happening to the water and ice in both processes.

Part II (Quantitative)

1. Place 1-2 ml of tap water in a test tube and place a thermometer in the test tube. (Use a #2 one-hole stopper to center the thermometer in the test tube and record the initial temperature of the water.)
2. Place the test tube and water in the beaker of rock salt and ice and read the temperature of the system at 15-second intervals for 10 minutes. (Place a second thermometer in the rock salt and ice mixture and record the temperature of the ice bath.)

3. Remove the test tube from the rock salt and ice and place the test tube in a beaker of room temperature water reading the temperature every 15 seconds for 10 minutes. (Use a second thermometer to measure the water temperature in the beaker.)
4. Graph the results of steps 2 and 3 (temperature as a function of time).

Data – Part 1 – Observations:

1.
2.
3.
4.
5.

Data: Part II: (Sample data is included on the last page). Graph is included on 4th page

Freezing		Melting	
Time-Freezing	Temperature-Freezing	Time – Melting	Temperature-Melting
1		1	
2		2	
3		3	
4		4	
5		5	
6		6	
7		7	
8		8	
9		9	
10		10	
11		11	
12		12	
13		13	
14		14	
15		15	
16		16	
17		17	
18		18	
19		19	
20		20	
21		21	
22		22	

23		23	
24		24	
25		25	
26		26	
27		27	
28		28	
29		29	
30		30	
31		31	
32		32	
33		33	
34		34	
35		35	
36		36	
37		37	
38		38	
39		39	
40		40	

Conclusion:

1. How did Part II differ from Part I?
2. What happens to the system's temperature when the water freezes? When the ice melts?
3. What do you think is happening to the energy that is being exchanged in both systems? (What happens to the heat energy as the water freezes in the first situation and ice melts in the second situation?)

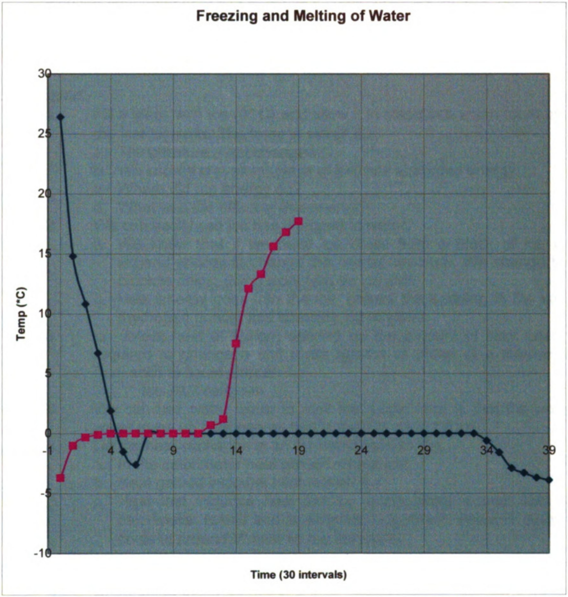
1. Students can see from their data the ice melts in half the time it takes it to freeze.

2. In both cases the temperature was a constant 0°C.

3. As the water freezes it needs to lose energy so the molecules can get closer together to form the ice crystals. (Lattice energy) As the ice melts the same amount of energy needs to be absorbed to melt the crystal. (This energy is stored as potential energy in the liquid phase.) This potential energy is called the heat of fusion or the latent heat of fusion.

Lab 16 – Phase Changes (Freezing and Melting) – Teacher's Edition

Time	Freezing	Melting
0	26.4	-3.7
1	14.8	-1
2	10.8	-0.3
3	6.7	-0.1
4	1.9	0
5	-1.5	0
6	-2.6	0
7	0	0
8	0	0
9	0	0
10	0	0
11	0	0
12	0	0.7
13	0	1.2
14	0	7.5
15	0	12.1
16	0	13.3
17	0	15.6
18	0	16.8
19	0	17.7
20	0	
21	0	
22	0	
23	0	
24	0	
25	0	
26	0	
27	0	
28	0	
29	0	
30	0	
31	0	
32	0	
33	0	
34	-0.6	
35	-1.6	
36	-2.9	
37	-3.3	
38	-3.7	
39	-3.9	
40		


Freezing and Melting of Water
30
25
20
15
10
5
0
-5
-10
Temp (°C)
-1
4
9
14
19
24
29
34
39
Time (30 intervals)

Lab 17 – Heat of Fusion – Teacher's Edition

Purpose:

To measure the amount of heat energy (calories or Joules) associated with the change of phase of water as it changes from solid to liquid phase.

$$H_20_{(S)} + \underset{(H_f)}{\text{energy}} \longrightarrow H_20_{(L)}$$

Background:

1. Fill a glass with ice (0° C) and allow it to stand in a warm room until the last bit melts. The temp is still 0° C.
   a. Temperature – not changed
   b. We know the system (glass of ice) has absorbed energy.
   c. Where did the energy go?
   d. What was the effect of this energy?
2. We can easily see ice has changed to water.
   a. We know that if we need ice chips from a block of ice we expend energy to change the crystal structure. We change the block to chips, doing work with an ice pick
   b. Heat energy goes into the ice, breaks the bonding in the solid (hydrogen bonds) and converts ice to water.
3. L_f (latent heat of fusion) defined as the amount of heat energy required to change a unit mass (grams or mole) of a substance from solid to liquid phase.
   Ice 79.7 cal/gram
4. We can use warm water to melt ice. Logic here is that the warm water gives up heat energy that is used to melt the ice.
5. Do the heat exchange in an insulated calorimeter.
   a. In the calorimeter heat gained = heat lost
   b. Heat gained includes heat to melt ice
   c. Heat lost includes heat lost by warm water + heat lost by calorimeter (small and is sometimes ignored). Assume system cools to around 5° after all the ice melts.

Procedure:

1. Need warm water 15-20° C above room temperature (use 40-43°C tap water).
2. Note the type of calorimeter (constant pressure) that you are using.
   a. 2 Styrofoam cups with a lid (or b)
   b. Aluminum calorimeter with an inner and outer cup (Do not find mass of the ring)
3. Find the mass of the calorimeter cup.
4. Add water to the cup 40-43° C and find the mass of the cup and the warm water.

5. Find the T_i for the warm water before you start to add the ice (stir water and measure the temperature).
6. Obtain your ice in a Styrofoam cup, dry the surface of the ice with a paper towel and then add to the warm water. (Do not splash).
7. Continue to add ice until the temperature is around 5°C (This is about as low as is needed), lower temperature may cause condensation on the calorimeter.
8. Control the ice addition of the end so it melts and does not need to be removed.
9. Measure the final temperature and find the mass of the calorimeter, warm water and ice (now ice water).
10. Compute the heat lost and heat gained and compute the heat of fusion.
11. Partners should work together with one another, each doing their own trial.

Data:

Measurements	Trial 1	Trial 2
1. Mass of calorimeter cup	11.39g	11.38g
2. Mass of calorimeter cup + warm water	104.07g	94.83g
3. Mass of calorimeter cup + warm water + ice water (after ice melts)	151.07g	129.52g
4. T_i - warm water + calorimeter	43.7°C	42.4°C
5. T_f – water + calorimeter + ice water	2.5°C	7.7°C

Lab 17 – Heat of Fusion – Teacher's Edition

Calculations:

Calculations	Trial 1	Trial 2
1. Mass of warm water	92.68g	83.45g
2. Mass of ice	47.00g	34.69g
3. C = calorimeter	5 cal/°C	5 cal/°C
4. ΔT – warm water + calorimeter	41.2°C	34.7°C
5. Calories lost by calorimeter	206 cal	174 cal
6. Calories lost by water	3818 cal	2896 cal
7. Total calories lost	4024 cal	3070 cal
8. Calories used to warm water formed by melted ice	118 cal	267 cal
9. Calories used to melt ice	$47 \bullet H_f$	$34.7 \bullet H_f$
10. Calories used to melt 1 gram of ice	83.1 cal/g	80.8 cal/g
11. Calories used to melt 1 mole of ice	1.496 kcal/mol	1.454 kcal/mol
12. Known value of H_f	79.7 cal/g	79.7 cal/g
13. Absolute error	3.4	1.1
14. % error	4.3%	1.3%

Lab 17 – Heat of Fusion – Teacher's Edition

Sample Calculation for Best Trial:

Calculations	Trial 2
1. Mass of warm water	94.83g – 11.38g = 83.45g
2. Mass of ice	129.52g – 94.83g = 34.69g
3. C = calorimeter	5.0 cal/°C
4. ΔT – warm water + calorimeter	42.4°C – 7.7°C = 34.7°C
5. Calories lost by calorimeter	5.0 cal/°C • 34.7 °C = 174 cal
6. Calories lost by water	83.45g • 34.7°C • 1 cal/g • °C = 2896 cal
7. Total calories lost	2896 cal + 174 cal = 3070 cal
8. Calories used to warm water formed by melted ice	34.7g • 7.7°C • 1 cal/g • °C = 267 cal
9. Calories used to melt ice	3070 cal – 267 cal = 2803 cal
10. Calories used to melt 1 gram of ice	2803 cal/34.7g = 80.8 cal/g
11. Calories used to melt 1 mole of ice	80.8 cal/g • 18 g/mol = 1.45 cal/mol
12. Known value of H_f	79.7 cal/g
13. Absolute error	80.8 cal/g – 79.7 cal/g = 1.1 cal/g
14. % error	1.1 cal/g/ 79.7 cal/g = .013 • 100 = 1.3%

Lab 17 – Heat of Fusion – Teacher's Edition

Conclusion:

1. What happens to the temperature of the ice as you observe it change from solid to liquid?
2. What becomes of the heat energy that is sued to melt the ice?
3. Why did the student dry the ice before dropping it into the calorimeter? How would the investigation be affected if the ice were not dried?
4. What is H_f - heat of fusion?
5. What is the value of H_f?
6. What are the principle sources of error in this experiment?
7. Reflect on the reason you did the investigation and if you were able to achieve the goal.

1. As the ice changes from cold to liquid its temperature remains at a constant 0°.

2. The heat energy that is used to melt the ice is stored as potential energy in the water that results from the melted ice.

3. The student dried the ice to remove already melted water from the ice's surface. This melted water would be included as ice and would already have absorbed the heat of fusion before it was placed in the calorimeter. This introduces a source error.

4. The heat of fusion is defined as the energy needed to melt 1 gram or 1 mole of ice at 0°C.

5. The accepted values of the heat of fusion are 79.7 cal/g or 1.43 kcal/mol.

6. Sources of error in this experiment include water splash when adding ice, not drying the ice before adding it to the calorimeter, and students not keeping good track of the heat lost and gained in the experiment.

7. Students wanted to see if they could measure the heat needed to melt one gram or one mole of ice. Their % error gives an indication of their ability to reach this goal.

Lab 17 – Heat of Fusion – Teacher's Edition

Teacher Tips:

1. The warm water in the calorimeter needs to be as much above room temperature as it was initially below room temperature. Using these technique students can cancel the heating and cooling effects of the room on the calorimeter.
2. Drying the ice removes water that results from premature surface melting of the ice. This water has already absorbed heat and melted but will be included as solid ice if allowed to enter the calorimeter. This is an additional source of error.
3. Add ice until the system cools to about 5°C (lower temperature can cause condensation and introduce another source of error.
4. Place the ice in a second covered cup and dry each piece before adding it to the calorimeter.

Lab 18 – Boiling Point of a Liquid – Teacher's Edition

Purpose:

To use the laboratory setup demonstrated in class to measure the boiling points of four unknown liquids. Proper technique should allow the identification of each liquid.

Procedure:

Students will write out the procedure based on their class notes.

1. Set up the apparatus like the diagram provided with the lab.
2. Teachers make certain the vapor is condensed away from the flame (The test tube where the vapor condenses should be in an ice water bath).
3. Place boiling chips in the test tube to ensure the formation of small bubbles in the boiling process (the boiling chips help prevent bumping – formation of large bubbles).
4. The height of the test tube may need to be adjusted 3-5 cm above the burner stand to ensure the liquid does not boil away too fast. Teachers can experiment with this height to ensure a rise of 5° for every 15 second time interval. Students should use 3-4 ml of liquid in each trial.
5. Students should take a 0 reading and then read every 15 seconds until the liquid is almost gone. The process will take between 6 and 10 minutes.
6. If you choose to do volatile liquids (wood alcohol – methanol and denatured alcohol – ethanol) you should not heat the liquids with a direct flame. Place boiling chips in the test tube and heat these liquids in a boiling water bath. Boiling chips should also be placed in the water bath. Methanol boils around 66°C and ethanol boils around 80°C. You could also use isopropynol which also boils around 80°C. Again make certain the vapors are condensed away from the flame in an ice water bath. You may want to do the volatile liquids as a demo and have the students do water and salt water.

Students will include a diagram of the apparatus that was set up in class (imitation is the sincerest form of flattery).

Lab 18 – Boiling Point of a Liquid – Teacher's Edition

Data:

Time	Liquid 1	Liquid 2	Liquid 3	Liquid 4
0				
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				
35				
36				
37				
38				
39				
40				

Lab 18 – Boiling Point of a Liquid – Teacher's Edition

Graph data on graph paper provided or use Excel.

Conclusion:

1. What happens to the temperature of each liquid as it starts to boil?

When a liquid begins to boil the temperature remains at a constant
value (its boiling point).

2. What is happening to heat energy from the burner as the liquid begins to boil?

The heat energy is used to overcome the intermolecular forces that
hold the molecules together. This energy increases the potential
energy of the system and this energy is stored in the gas phase.

3. What happens to heat energy as a vapor (gas) condenses to form a liquid?

The potential energy stored in the gas phase is lost as the molecules
condense to form a liquid.

4. If it takes longer for a liquid to boil does it mean the liquid gets hotter? Explain.

If it takes longer it means there is more liquid that needs more time
to reach the boiling point.

5. Do all the graphs look the same? How are they the same? How are they different?

All the graphs have the same basic shape. They all plateau at their
boiling point, however, the plateaus are at different temperatures.

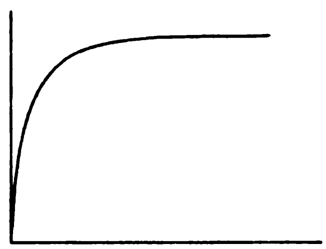
6. Do all the graphs have a flat section? What are the temperatures of the flat section?

All student graphs should have a flat section. Boiling points should
reflect water at 100°C, salt water at 102-107°C, methanol at 66°C,
ethanol or isopropynol at 80°C.

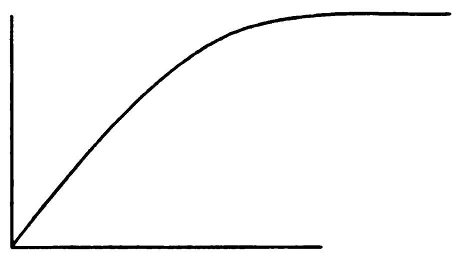
7. Was the temperature the same in all the test tubes once the liquid started to boil?

Each test tube had a liquid that has a specific boiling point
characteristic of that liquid.

8. Does the boiling temperature depend on the amount of liquid used? What if you used 3 ml in one trial and 12 ml in the next trial? What would the graph of each trial look like? (sketch the graph). Boiling points are the same for each sample, it just takes longer to boil away the larger sample.



3 ml



12 ml

9. What does a difference in boiling points reveal?

A difference in boiling point reveals that the liquids are not the same.

10. Is boiling point a characteristic property? Why?

Boiling point is a characteristic property because it does not depend
on the amount of the sample and it will identify the liquid in question.

This experiment is from the Introductory Physical Science Program (IPS).

Lab 19 – Heat of Vaporization – Teacher's Edition

Purpose:

To observe the amount of heat energy (calories or Joules) associated with the change of phase of water as it changes from liquid to vapor phase. Measure the amount of heat associated with the vaporization of 1 gram or 1 mole of water.

$$H_2O_{(liq)} \longrightarrow H_2O_{(gas)} + \text{energy}$$

Background

1. When water is heated and temperature rises toward the boiling point, bubbles form in the liquid (water bubbles filled with H_2O) rise through the liquid and break at the surface. The formation of the bubbles is termed boiling and the breaking of the bubbles at the surface (allowing the molecules to enter the gas phase) is called evaporation. The combination of boiling and evaporation is termed vaporization.
2. We have noticed that the boiling water and the vapor are at the same temperature (100° C) – 212° F
3. It is evident that heat is being absorbed however the phase change occurs with no change in temperature.
4. The energy is used to do work to overcome the forces that hold the molecules together (Dipole – dipole) hydrogen bonding.
5. Additionally, the air that surrounds the vessel (end of hose) is also pushed back to make room for the escaping molecules (remember water displaces the air and is not absorbed by the air).
6. When molecules of the vapor condense back to liquid phase the extra heat that was stored in the molecular gas phase is released to the local environment (in our case, water in the calorimeter).
7. The heat of vaporization is the amount of energy (in the form of heat) needed to change 1 gram or 1 mole of water from the liquid to the gas phase with no change in temperature.
8. The heat of condensation (equal to H_{vap}) can be measured by allowing a known mass of steam at a know temperature (100° C) to condense into a known calorimeter with a known mass of water and noting the rise in temperature.
9. To evaluate the exchange we use the following expression:

Heat lost by + heat lost by H_2O(L) = heat gained by H_2O + heat gained by

vapor	from condensed	in calorimeter	calorimeter
H vap • mass	Q= g steam • ΔT	g • ΔT • c	Heat factor for
of condensed	for cooling • c		
calorimeter •ΔT			
vapor			

Lab 19 – Heat of Vaporization – Teacher's Edition

Procedure:

1. Set up a steam boiler about 1/3 full of water.
   a. Prepare the calorimeter 2/3 full of 5°C water
   b. Record the air pressure
2. We need to set up a water trap between the boiler and calorimeter.
   a. We only want steam to enter the calorimeter.
   b. Need to prevent hot water that may condense along the way through the tube from entering the calorimeter.
   c. The water trap will collect the condensed water and permit the steam to continue.
3. Find the mass of the calorimeter cup empty.
4. Add 5° C water to the cup and find the mass of the cup and water.
5. Measure the temperature of the steam.
6. Read T_i for the cold water, introduce the steam to the cold water and allow the temperature to rise as far above room temperature as it was below room temperature.
7. Remove the hose – allow system to reach equilibrium and read the equilibrium temperature T_{eq}
8. Find the mass of the calorimeter and water and condensed steam.
9. Compute the value of H_{vap} and compare to accepted value of 539.6 cal/gram.

Data:

Measurements	Trial 1	Trial 2
1. Mass of calorimeter cup	11.39g	
2. Mass of calorimeter cup + 3-5° C water (ice water)	130.95g	
3. T_i – cal + H_2O	6.7°C	
4. T_i – steam	99.0°C	
5. T_{eq} – water + cal final	49.7°C	
6. Mass of water + cal. cup + condensed steam	139.42g	

Lab 19 – Heat of Vaporization – Teacher's Edition

Calculations:

Calculations	Trial 1	Trial 2
1. Mass of water	119.56g	
2. Calorimeter constant	5.0 cal/°C	
3. Mass of steam	8.47g	
4. ΔT for water and calorimeter	43.0°C	
5. ΔT for water from condensed steam	49.3°C	
6. Calories gained by calorimeter	215 cal	
7. Calories gained by water	5141 cal	
8. Total calories gained	5356 cal	
9. Calories lost by water formed from condensed steam as it cools from T_i – steam to T_{eq}	418 cal	
10. Calories lost by steam as it condenses at 100° C.	4938 cal	
11. H_{vap} of water = heat of condensation	583 cal/g	
12. Accepted value for H_{vap}	539.6 cal/g	
13. Absolute error +	43.4 cal	
14. % error	8.0%	

Lab 19 – Heat of Vaporization – Teacher's Edition

Sample Calculations:

Calculations	Trial 1
1. Mass of water	130.95 g – 11.39 g = 119.56 g
2. Calorimeter constant	5.0 cal/°C
3. Mass of steam	139.42g – 130.95g = 8.47g
4.ΔT for water and calorimeter	49.7°C – 6.7°C = 43.0 °C
5. ΔT for water from condensed steam	99.0°C – 49.7°C = 49.3°C
6. Calories gained by calorimeter	5.0 cal/°C * 43°C = 215 cal
7. Calories gained by water	119.56g • 43°C • 1 cal/g • °C = 5141 cal
8. Total calories gained	5141 cal + 215 cal = 5356 cal
9. Calories lost by water formed from condensed steam as it cools from T_i – steam to T_{eq}	8.47 g • 49.3 °C • 1 cal/g • °C = 418 cal
10. Calories lost by steam as it condenses at 100° C.	5356 cal – 418 cal = 4938 cal
11. H_{vap} of water = heat of condensation	4938 cal/8.47 g = 583 cal/g
12. Accepted value for H_{vap}	539.6 cal/g
13. Absolute error +	583 cal/g – 539.6 cal/g = 43.4 cal/g
14. % error	43.4 cal/g / 539.6 cal/g = .080 °• 100 = 8.0%

Lab 19 – Heat of Vaporization – Teacher's Edition

Conclusion:

1. What happens to the temperature of the water as it changes from liquid to vapor?
2. What does the heat from the gas burner do to the water in the boiler? What is this heat energy used for?
3. What happens when the water vapor from the boiler condenses in the calorimeter (2 things)?
4. What are the heat of vaporization and the heat of condensation?
5. Why did we use a water trap?
6. How would its absence affect your results?

1. The temperature of the water remains at a constant 100°C.

2. Heat from the laboratory burner is used to change liquid water to water vapor and overcomes the intermolecular forces that hold the water together (hydrogen bonds). This heat energy is stored as potential energy in the gas phase.

3. When the water vapor condenses it releases the stored heat of vaporization on condensation to the water and to calorimeter. Additionally, the water that results from the steam then cools to the equilibrium temperature and loses more energy.

4. The heat of vaporization and condensation refers to the energy that is used or given up to achieve the desired phase change (vaporization or condensation).

5. Students use the water trap to prevent condensed water from dripping into the calorimeter. Our goal is to condense only steam in the calorimeter.

6. Any water that condenses in the hose and then runs into the calorimeter has already lost its energy of condensation while in the hose. If this water drips into the calorimeter it will be assumed to be steam and will introduce a source of error into the final results.

Lab 19 – Heat of Vaporization – Teacher's Edition

Teacher Tips:

1. The steam generator can be placed on a hot plate or students can use a laboratory burner to heat the water.
2. The use of a steam trap, traps premature condensation and therefore ensures that only steam enters the calorimeter.
3. Use a hot pad to handle the steam hose.
4. When water vapor condenses it releases 540 calories of heat per gram of stored potential energy. If the steam condenses prematurely and water droplets form in the hose, that energy is lost before the steam enters the calorimeter. However, the pressure of the system will force this water into the calorimeter and it will be included as condensed steam. This will be a student's largest source of error.
5. Heat is lost from two sources in this experiment.
   a. Each gram of steam loses 540 calories/gram when it condenses at 100°C.
   b. The 10-12 grams of condensed water that forms and then cools to the equilibrium temperature will also lose heat ($Q = \text{grams} \bullet \Delta T \bullet C$.
6. The heat that is gained in this experiment includes:
   a. Heat gained by the cold water.
   b. Heat gained by the calorimeter.

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