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USING ALTERNATIVE ENERGY CONCEPTS AND HANDS-ON ACTIVITIES TO TEACH PHYSICS BENCHMARKS AND INCAREASE STUDENT MOTIVATION: THERMODYNAMICS, OPTICS AND ELECTRICITY

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USING ALTERNATIVE ENERGY CONCEPTS AND HANDS-ON ACTIVITIES TO TEACH PHYSICS BENCHMARKS AND INCREASE STUDENT MOTIVATION: THERMODYNAMICS, OPTICS AND ELECTRICITY

VOLUME I

By

Jerri Lynn Amos Osmar

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ABSTRACT

USING HANDS-ON ACTIVITIES AND ALTERNATIVE ENERGY CONCEPTS TO TEACH PHYSICS BENCHMARKS AND INCREASE STUDENT MOTIVATION

By

JerriLynn Amos Osmar

Thermodynamics, optics and electricity benchmarks were taught in a high school college prep physics class in units that focused on alternative energy. Instructional methods included laboratory experiments, hands-on building projects, experimental design, authentic research, internet research, critical reading, practicing math problems, and study guides and lecture notes which made heavy use of labeled drawings.

The instructor made use of data from prior knowledge surveys, post tests, post surveys, grades on tests, quizzes and assignments, attendance and a notebook of anecdotal commentary written each day at the end of class. Post surveys and the notebook of anecdotal comments show that engagement was highest for hands-on activities of all types. In many cases, motivation to do the activities did not carry through to thinking critically about the underlying concepts or doing written work or work at home.

The topic of alternative energy supports the benchmarks effectively, is of current interest in society and offers opportunity for hands-on activities and authentic research including practice with experimental design. However, the topic itself does not seem to affect student motivation. Gains in student knowledge covered by the benchmarks for scientific inquiry, thermodynamics, optics and electricity were substantial as evidenced by the difference in scores between pretests and post tests.

THIS THESIS IS WRITTEN

IN REMEMBRANCE OF

Norris Hotchkin and Gladys Klotz
who loved learning and trying new things
right up through their final years.

IN DEDICATION TO MY FAMILY

Parents Jerry and Elaine Amos
who have always encouraged and supported me when I have chosen
a new direction or tackled a big project.

Sons Jerren, Carter and Clark Osmar
who are thoughtful, kind, intellectual, adventurous, hardworking, moral individuals
in spite of, or due to, having a mom who has always split her time between family
and deep immersion in some endeavor.
Our conversations give me food for thought and inspiration for change.

Daughter-in-law Sarah Berry
who is herself a teacher.
Her enthusiasm, energy, confidence and positive attitude bring me great happiness.

Granddaughter Eleanor Elizabeth
who arrived amidst my work on this project
and is herself a "project" on which I plan to devote much time and energy.

Fiancé Lance Wynn
who has been very patient throughout the research, writing and typing of this thesis
even though our conversations on my favorite science topics "make his head hurt"!

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INTRODUCTION

OBSERVATIONS

Student apathy, boredom and under-achievement seem epidemic at Owosso High School. Students appear to be most excited when learning about current discoveries or cutting-edge technology and when actively engaged in projects that affect their life and benefit society. However, these aspects are not often part of their classroom experience. Politicians and business people want that to change. Our governor, Jennifer Granholm, is pushing for Michigan to be a leader in the new alternative energy industry. She cites the National Renewable Energy Lab prediction that 20 million new jobs will be created in that field over the next 20 years (Duffy, 2008 and Pluta, 2008). Other political officials as well as business executives lament the lack of workers that are skilled and knowledgeable in science and technology (Greenhouse, 1992 and Wilgoren, 2003). We need to change the way science is taught, motivating students to become intellectually engaged and increasing the number of those choosing to pursue programs of study and careers in science. It will take people with solid science backgrounds to make our state a leader in alternative energy.

In my own physics classroom, I begin the year with a unit on origins of the universe and particle physics. I continually update using the most current information that I can find. We build cloud chambers and do experiments with cosmic ray detectors. We tour the cyclotron at Michigan State University and view the control room of the SOAR Telescope. Some years we also visit the nuclear reactor at the University of Michigan. We probe deep philosophical questions, sometimes including religion. A Geiger counter supplements the lessons on radioactivity and we draw the guts of a nuclear power plant. I use the notes I took during a Brian Greene lecture to guide students deep into the mysteries of string theory.

During that unit I see sparks in the students' eyes and hear the hunger in their insightful questions. I have had students tell me at the conclusion of that unit that they have changed their mind about what they want to pursue in college.

But then we start in with the chapters at the front of the book and their faces drop. The topics are a little dry, perhaps made drier by the fact that they aren't learned as part of engrossing, currently meaningful projects, but as isolated scenarios where they are distant observers rather than active participants. There are story problems about children pulling sleds up hills and airplanes flying toward 63 degrees.

As the chapters go on, students' eyes lose their bright spark. The hands-on activities and the current news flashes I include grab their interest. But it is not sustained the way it was in the first unit. These labs and activities are generally designed just for the purpose of teaching concepts and are not authentic projects from which the student or society will benefit. High school students seem to crave being involved in activities that they perceive as being part of the real world. Some students seem to hold onto the hope that the "boring" stuff is temporary and that we will soon get back to really exciting things. But by chapter 4 or 5 most have given up hope.

Last year I noticed that a topic in Environmental Science, alternative energy, *really* interested the students. We made diesel fuel as one of the activities. Several steps took multiple days to complete, so the whole project lasted a couple of weeks. Students were so excited that their questions took up a large portion of class time. Students that quite often skipped class were sure to be there on days when we did another step on the diesel procedure. One girl who had a grade of about 40%, went home and loaded the back of her pick-up truck with bags and bags of wood ashes. We used them to make lye, one of the ingredients in the diesel recipe. Another boy who rarely did anything in class, spent a couple of days on his own time after school trying to round up an engine that we could use to test our finished product.

The physics students also seemed quite taken by alternative energy topics. They found out that we were making diesel fuel in Environmental Science and wanted copies of the recipe. It fascinated them that it could be made from scratch using used cooking oil, wood ashes and alcohol. Most of them had cars and were feeling the pinch of high gas prices. The interest among the physics students remained high as we began learning about heat engines, geothermal heat pumps and hybrid cars in the thermodynamics unit of their class.

The contrast between the level of energy in the classroom when students are interested and when they are bored is incredible. Although not all students are interested in the same topics, it seems that if a certain number of students get excited about a topic their enthusiasm spreads to the rest of the class. What can be done to achieve this level of interest more consistently while still covering the material dictated by Michigan benchmarks? And do students actually learn more when they are actively engaged, or are they just busier?

PROBLEM AND HYPOTHESIS

The observations I have made of my own students are not unusual. It seems that the problem is national in scope and serious. Thomas Friedman in The World Is Flat (2006) warns that the US student has fallen way behind students in other countries in terms of work ethic, and work ethic is especially important in the pursuit of science. It's hard to learn the fundamentals, and for most it is not "fun". He also points out that this is already having an adverse effect on the job outlook for US graduates in technical fields. Companies aren't just outsourcing because foreign labor is cheaper. Foreign workers are more productive. They work harder. And they put more effort into continually upgrading their skills (Friedman, 2006). I'm afraid that the longer students stay in the mode of being bored and not putting forth effort, the more likely it is to become a lifelong habit.

The Bill and Melinda Gates Foundation targeted high schools as being in dire need of reform. They cite low student motivation as a major concern (Greene, 2006). One consequence of low motivation is low test scores. The scores that I see in my classroom are mirrored across the country. According to the National Assessment of Educational Progress, twelfth graders don't have the skills they need: 64% are not proficient in reading, 83% are not proficient in math, and 82% are not proficient in science (Greene, 2006).

Another consequence of low motivation, lack of interest and poor work ethic is the US drop out rate. In 2006 the rate had risen to 30% of all 17 year olds. Many statistics issued by high school administrations sound much better than this because in figuring their drop out rate, they count only students who made it to the 12^{th} grade, ignoring the ones who dropped out before that (Peterson, 2006). For those that do make it to high school graduation, the lack of motivation resulting in (and from?) year after year of disengagement and minimal effort has certainly not left them prepared for competing in the global economy (Friedman, 2006). Something must be done.

When presented with 11^{th} and 12^{th} grade students who have already been bored by science for years and whose lack of effort has become habitual, the task to motivate and engage is neither easy nor quick. It's necessary to make some very significant changes in the way we attempt to educate, beginning in grades that come before high school. As educators, we must do what we can to help solve the part of the problem to which we may be contributing.

I propose to teach thermodynamics, optics and electricity benchmarks using hands-on activities in the field of alternative energy. It is my expectation that *doing* science rather than just learning content, will motivate students to be physically and intellectually engaged. The rationale for choosing alternative energy as the topic of study relates to Michigan's economy and the future well-being of ecosystems. We are in great need of engineers and entrepreneurs who can pioneer the fledgling industry of alternative energy. Perhaps doing science in this field in high school will instill a feeling that individuals can tackle global problems and that science is one tool at their disposal. These units may also influence the path students choose to follow in college and help guide decisions they make in their daily lives.

REVIEW OF THE LITERATURE

"First, you have to have a question. It has to be your own question because then you'll really care about the answer." (Church, 1992)

There is a significant drop in student motivation with regards to science between the primary and secondary years (Darby, 2007). A review of the literature shows global consensus in regards to using current real world issues as topics to increase student motivation and make the relevant. But there is controversy surrounding the practice of actually doing science rather than simply learning about science. Some believe that in many cases hands-on science does not engage students intellectually and does not result in greater understanding of content standards (Ruby, 2001). Ruby's data showed positive gains in knowledge. It appears that studies where quantitative data do indicate significant gains in understanding, the role of the teacher and the pedagogical methods employed played a crucial part in the success (Kirschner et al, 2006).

Chester Flinn (2006), writing in *Education Today* , analyzed high school education. Two of his findings relate directly to this thesis. Course offerings are not reflective of the skills and knowledge that are needed in the real world. And, the curriculum has many students "bored, turned off...and tuned out...". He calls for a large variety of experimental approaches to tackle the major problems facing schools rather than one blanket strategy handed down from the federal government. One specific strategy he suggests is tailoring the benchmarks to the needs of the current job market.

M. P. Silverman (1995), in an article for the *American Journal of Physics*, states that students are only motivated to learn something if it is their own curiosity that initiated the quest for the knowledge. Most students don't take physics because they are driven by their own curiosity. They usually sign up because it is a prerequisite for things they really do want to do. Many don't enter the classroom in a highly motivated state. Silverman proposes to increase intrinsic motivation by having students "*learning* physics and not just learning *about* physics". He points out that although science is basically a field of inquiry, it's presented in courses as a set of already-known facts to be memorized. Introduce inquiry and curiosity, and thus the motivation to learn, would flourish.

Linda Darby (2007) observed a seventh grade classroom weekly over the course of one school year. At the end of the study, she concluded that the type of science students do in school can't be the same as science done by real researchers. The goals of the two are different. As educators, teaching science concepts takes priority. However, Darby points out that learning to do science involves skills that will be useful in a whole spectrum of human activities. Students practice "focus(ing) their attention and powers of observation, *doing* something with results", recognizing what the question is, and making use of existing knowledge to interpret and utilize the new knowledge. These skills will be valuable when "dealing with people, new situations, old situations, thinking rationally, logically and creatively". Thought of in this light, fostering scientific thinking is even more valuable than teaching the science content. And if the student becomes hooked on *doing* science, the drive to discover will be "intrinsically motivating".

There is evidence that the topic or theme the instructor chooses as the vehicle to convey knowledge is important. James Kushman (2007) studied a middle school classroom that was working on an endangered species project. He believes the project excited the students "because of children's natural love of animals and because it was a timely environmental issue". He discusses using thematic units as an effective practice along with having projects that require skills and knowledge from multiple subjects, emphasizing problem solving and creative thinking, and allowing the projects to be student-directed with the teacher's role being that of a facilitator. However, if the teacher chooses a current topic, like most environmental issues, the material must be continually updated.

Studies done by researchers both inside and outside the United States voice the importance of teaching concepts and skills that will help students grapple with the environmental problems that face our planet. In a paper presented at the Sixth International Conference of the Balkan Physical Union, Zalkida Hadzibegovic (2007) argued that in countries such as Bosnia and Herzogovina where many reforms are occurring, now is a good time to change physics curriculum to include environmental education with the goal of sustainable development driving the content. Hadzibegovic administered questionnaires to college professors. Data indicated that students' interest in environmental topics presented in physics classes was low, and that there is a need for high school teachers to impress upon their students the urgency and importance of scientific endeavor in this field.

Grace Umoren (2007) published a study in Educational Research and Review which involved 480 secondary students from six schools in Nigeria. One group followed a traditional science curriculum and the other a program called Curriculum in Science-Technology-Society. She perceived that teaching methods used were actually precluding many students from a career in the sciences. The traditional curriculum is "poorly suited to the intellectual development of the majority of students" and furthermore they are unable to use the science they learn in a practical everyday way. Her recommendations, after analysis of the quantitative data, include making technology and societal problems an integral part of the science curriculum and taking care to teach the concepts in a way that students see how they can use the information to improve their own quality of life and the quality of life for their families and communities. Agriculture and making use of the country's vast untapped natural resources are two areas in Nigeria where students could put their new knowledge to immediate use.

Many studies show that topics that motivate students often have to do with real life issues. M. P. Silverman (1995) wrote that students will "devour" information on physics topics that they would have labeled as boring when taught traditionally, if that information relates to a project they have chosen on their own. He found that students were especially interested in investigating topics that relate to their own well being, like radon exposure. He further points out that students sit in science classes thinking they will never use any of the science they are being forced to learn. Instructors need to work hard at showing students that the skills they learn while *doing* science will be useful in other areas of their life.

Barbara Crawford, in her study of a biology classroom (2000), disclosed characteristics that she feels are most important for inquiry-based learning. Among these that the learning take place within the context of an authentic real world problem that required the students to "grapple with data". The problems that these students worked on included water quality testing of local aquatic environments, designing a constructed wetland for a contractor, and evaluating winter lettuces for a commercial grower in their community.

Many researchers have mentioned *doing* science rather than just learning about science. The National Research Council (2008), using data from a multitude of recent studies, recommends that students engage in the scientific process as the preferred method of learning the concepts. They believe that textbooks treat the two as separate disciplines and that process and content should be joined as one. Students need to construct their own knowledge and "practice good habits of scientific research" (Christensen, 1995).

Ronna Turner (et al, 2007) in a paper presented at the annual meeting of the American Educational Research Association, discuss a program called "K-12, I Do Science" or "KIDS". In this program, inquiry based hands-on activities are aligned closely with content standards. The students' natural curiosity motivates them to learn. Data collected by trained classroom observers shows that 80% of students were actively engaged. (But the researchers did not specify the type of engagement.) Students in this program showed greater gains in content knowledge than those in traditional programs. Researchers found that the components of the program most responsible for engagement of students were the testing of hypotheses and manipulation of equipment.

The Turner paper (2007) necessitates an important distinction. When we speak of engagement, does simply manipulating equipment count as engagement? Or does the student need to be intellectually active as well? In the literature, when both are involved the activity is often labeled as "hands-on minds-on".

Lillian McDermott (1993) wrote an article in the American Journal of Physics that addresses the hands-on minds-on issue. She analyzed 15 years of research on the learning and teaching of physics that had been published by physicists. Three of her conclusions are especially noteworthy.

First, she says it is not enough to have students engage in quantitative problem solving. Qualitative approaches are essential for learning the concepts. One example she uses as evidence is a study of over 500 university and high school students that could successfully use Ohm's Law and Kirchoff's Rules. Only 15% of these students could explain why certain bulbs in parallel and series circuits were brighter than others.

Secondly, after a course taught by traditional methods, most students were unable to connect what they had learned in class to anything in their everyday world. Students need lots of opportunities in the classroom to learn the concepts by physically manipulating real objects and figuring out how they work.

Thirdly, for students to internalize concepts, the student must be intellectually engaged, reasoning their way through the concept to convince themselves that it is logical and makes sense when meshed with their existing knowledge. Having a teacher tell the student the information, no matter how skilled the teacher, will not produce the same result.

Crawford (2000), in her study of a high school biology class, brings up a method for helping insure that students reason their way through an activity. She thinks the instructor was successful in his role of getting students cognitively involved by asking questions while the students were engaged in the activity. The questions asked *what* they were doing and *why* they were doing it or why they may have gotten the result they did. In addition, he quite often had students write a paragraph about what they did after the conclusion of the activity.

Edgar Corpuz and N. Rebello (2008) detail ways to get students intellectually involved while doing hands-on activities, in their paper discussing a study of students learning about friction. They began with an activity where students dragged a block across several types of surfaces, predicting ahead of time which would produce the most friction. This was an exploration activity whose goal was to access the students' prior knowledge. Students were instructed to write qualitative accounts of their understanding of what was happening, as well as to draw diagrams illustrating the qualitative description.

Later, the students participated in activities whose results did not mesh with their understanding of friction. (The most friction resulted from two smooth sheets rather than two rough surfaces due to electrical attraction.) Students had to make changes in their own cognitive model, and again explain it in qualitative sentences and labeled diagrams. Writing, drawing and adjusting their beliefs all required intellectual engagement. The teaching materials also made use of open-ended questions to be answered at certain points during the activities to cause students to think critically about their observations.

There were three groups of students in the study. One group learned the material through traditional lecture, one group by videotaped lecture and the third group by the activities described above. Post test results showed significantly higher gains for the group that engaged in the hands-on activities described above.

There have also been studies and articles written, whose authors conclude that real life or hands-on activities quite often fail to engage the student intellectually. Allen Ruby (2001) in a RAND Dissertation notes that the idea of hands-on science has been controversial in the United States for about 100 years. Douglas Morrison (1997), in his review for Scientific American of Alan Cromer's book Connected Knowledge: Science, Philosophy and Education, relates a story about parents at his school. The parents that were scientists were upset that the science curriculum had turned to students doing labs where they were not told what should happen or why things were happening, but had to figure it out on their own. They argued for more guidance during such activities to insure their students learned the concepts.

D. Hayes and his research associates (2006) assert that designing your curriculum around popular culture as a way of connecting to students' everyday life, while possibly increasing motivation, may not provide intellectual engagement. In accordance with this, David Zyngier (2007) in his symposium paper on *(Re)conceptualising Connectedness as a Pedagogy of Engagement*, cautions that attempts to connect curriculum to everyday life and future jobs programs often fail to actively engage the students in a cognitive way (Zyngier, 2007). And worse, he goes on to say, some careers these curricula prepare students for may not exist in the near future or may not have openings available. Zyngier's paper focuses on the at-risk student, but many of the conclusions he has drawn seem equally applicable to all students.

Other studies show a positive correlation between direct instruction and student learning and a negative correlation if students participated in discovery activities that were unguided. For these cases, discovery activities were only successful if students were first taught concepts in a traditional way, and then participated in structured activities and then finally were *guided* through discovery learning activities (Kirschner et al, 2006).

It seems the role of the teacher may be pivotal in the success or failure of an activity that is meant to be hands-on and minds-on, and whether the activity motivates students to learn. Crawford (2000), in reflecting on the instructor's role in a biology classroom, concluded that hands-on inquiry based projects require the teacher to take on a much more complex role than the traditional facilitator. This type of instruction places high demands on teachers as far as the level of involvement and the number of "hats" he must wear. An exceptionally effective part of the role is that of scientist. Before a water quality project, the teacher said to the class, "I don't really know what we're going to find out. It is really going to be interesting to get some data and get some baseline data for comparison, might just give us some ideas for questions we might want to ask further." Students feel like they are really uncovering something new. The instructor was also able to motivate the students by being very enthusiastic about the project himself and about the process of doing science. He also got right in there and did science with them. Students reported that his enthusiasm "rubbed off on them".

The student's in Crawford's study participated in interviews at the end of the year. Almost all of them said their favorite parts of the ecology unit were the field work activities. Most students gave positive comments about the challenge of "grappling with data". Two rated that aspect negatively, but one of the two followed up by saying that she was glad she learned how to do quality work. Most negative comments from students centered around "their discomfort with the pace and complexity of the work." Results of this study showed that students were motivated by the fact that this was real research, where the outcomes were not known.

Most of the research viewed on the topics of motivating students using real world hands-on minds-on activities made extensive use of both qualitative and quantitative data. Crawford (2000) who studied the high school biology classroom, made use of qualitative observations in the form of verbatim responses of students during interviews. She also categorized her written observations into categories of "critical incidences" and "teacher and student actions". Most of her data were of a qualitative nature and she recognized that communicating this type of data was a delicate balancing act between providing enough detail to fully describe the scenario and happenings, while not distracting from the main message by having it buried beneath excessive detail. She felt it was important to use a large amount of qualitative data to accurately portray the complexity of the classroom.

Alternative energy is the current real life issue that this thesis attempts to use as the vehicle for motivating students and teaching physics benchmarks. This topic is being taught at the post-secondary level. Two examples are Lansing Community College and Indiana University. Lansing Community College has several courses in this category, one example being a class on geothermal systems taught by Gary Dannemiller. Indiana University offers an undergraduate course called Environmental Physics P310 (Indiana University, 2008). Their course description states "...this course provides a wealth of applications of the theoretical laws of physics to (the) very real and demanding problems of the environment." It is an interdisciplinary course which investigates four areas: Identification of energy resources, energy conversion processes, energy utilization and environmental consequences of energy use.

Teaching of alternative energy concepts prior to the post secondary level seems to be most common at the middle school level as well as in high school biology and environmental science classes. With a lack of literature on teaching the *physics* of alternative energy at the high school level, especially in an activity-based way, it seems that the next step would be to institute programs at that level. If we could move this sort of curriculum into high schools perhaps students would be more likely to choose to pursue a science program in college. And it would allow for more rigor earlier in the university program.

STUDY POPULATION: DEMOGRAPHICS AND CONDITIONS

As of October 2007, Owosso Michigan had a population of 4,670. The median household income was $32,576. Seven and one-half percent of the workforce was unemployed. Eighty one percent of the adults have a high school diploma. Twenty two percent of those high school graduates also hold associate degrees and 19% have bachelor degrees. Most of the homes (66%) have price ranges between $50,000 and $99,000. The town has five private schools, five public elementary schools, one public middle school and one public high school. It also has a public alternative high school called Lincoln (National Relocation, 2007).

Owosso High School, which houses grades 9 through 12, had an enrollment of 1320 in the fall of 2007. Twenty seven percent of these students were categorized as economically disadvantaged, 69.6% were proficient in reading and 50.6% proficient in math (School Matters, 2007).

The study described in this thesis took place in the only physics class at Owosso High School. There were 13 students in the class at the beginning of the school year: six females and 7 males. By the time the units for this research began, one female had dropped and one male added the class. This resulted in a class of five females and eight males. Eleven of the students were unfamiliar to the instructor, never having had them as students before. Two of the male students were students from an astronomy/meteorology class that the instructor taught previously. Part way through the thesis units the class size dropped to 12.

Several weeks into the school year, and before the thesis units began, it became clear that the academic performance of this group of students was lower than previous years' physics classes. An analysis of the students' course history records showed an average math grade of B for the previous school year. Some had taken geometry and some had taken algebra 2. The average chemistry grade was also a B. The average overall grade point average however, was 3.36 which is not far below the 3.50 average I often see in my physics classes. However, physics students normally have math and science grades averaging at least B+.

This particular class met for one hour five days per week. The school day consisted of six one-hour classes. The school year was divided into two semesters of two marking periods each. The instructor was in her eighth year of teaching and this year she taught Chemistry and Environmental Science as well as Physics. These were taught in a fairly hands-on manner, so the room was often crowded with equipment. There were no lab aides this year resulting in less instruction time for students and less planning time for the instructor as both the instructor and students assumed lab aide duties.

SCIENCE CONCEPTS ADDRESSED IN THESE UNITS

THERMODYNAMICS AND OPTICS

Thermodynamics is the study of changes in heat, thermal energy and temperature. Students often confuse the three terms. Heat is the transfer of energy as a result of differences in temperature where temperature is a measure of the average kinetic energy of the particles that make up an object. Thermal energy is the total potential and kinetic energy of all of the particles that make up an object. Therefore, thermal energy is dependent upon size of the object. Two objects made of the same substance, having the same temperature will not contain the same amount of thermal energy. The larger one will contain more thermal energy as it contains more particles.

Heat capacity is a measure of how much energy it takes to raise the temperature of an object. Different substances have different heat capacities. Water has a very high heat capacity due to hydrogen bonding. It takes a lot of energy to raise the temperature of water. Because of this, water is an effective heat sink and is often used in solar energy systems. A relatively small amount of water can absorb a large amount of heat throughout the day, and then that heat is slowly released heating its surroundings.

When two objects of different temperatures come into contact, heat will flow from the warmer object to the cooler one until both are the same temperature. At this point there will be as much heat flowing from object A into object B as there is from B to A. The objects have reached thermal equilibrium. This final temperature depends upon the mass of the objects and their specific heat capacities. Solar hot water systems use this concept.

The thermal energy within a closed, isolated system is conserved. Doing work *on* the system or adding heat *to* the system, will result in a corresponding gain in thermal energy within the system. The only spontaneous changes which will occur in the system are those which result in greater entropy for the system as a whole. These laws govern the workings of heat engines.

The optics concepts used in this unit center around the relative properties of the various electromagnetic waves. The composition of an object dictates whether incoming radiation will be transmitted, reflected or absorbed. An object will absorb frequencies that match the natural frequency of the atoms in the material. The broader the range of the frequencies that can be absorbed by the absorbing material in a solar heating system the better, as they are radiated back out as infrared (heat). Materials that are not transparent to infrared waves are then used to trap the heat that was radiated.

ELECTRICITY

Fuel cells and batteries generate electricity by converting chemical energy to electrical energy. Unlike the battery, the reactants in a fuel cell continually enter the cell from outside. If electricity is supplied to such a system the reaction will run in the non-spontaneous direction producing chemical energy.

Photovoltaic cells convert light energy to electricity. Free electrons from an n-type material such as phosphorus, spontaneously move to a p-type material such as boron, on an adjacent plate. Incoming photons knock the electron back onto the n-type plate via the photoelectric effect. The electrons can then travel on an external circuit to make their way back to the p-type plate.

This flow of charged particles requires an unbroken path of conducting material, a source of electrons and a difference in potential to cause the charges to move. As charged particles move through any material they encounter the particles of the material.

The friction from the encounters releases heat and light and resists the flow of charges. The elements in heaters, toasters and the filaments in light bulbs work under this principle.

Current can be controlled in both series (one path) and parallel (multiple path) circuits by varying the resistance or the voltage. In a parallel circuit, charges can still flow if one of the paths develops a break, as with a broken filament of a burned out bulb, as they have more than one possible route back.

IMPLEMENTATION

DESCRIPTION OF UNITS

Two units based on alternative energy were used to investigate whether students would be motivated and learn content by *doing* science related to challenges that the world is currently facing. The units addressed the benchmarks for thermodynamics, some optics and electricity. Review of the current benchmarks for Physics issued by the State of Michigan indicates that those would be the best fit. In the thermodynamics unit we focused on solar hot water systems, heating air spaces with solar energy, geothermal heat pumps and Stirling engines as they relate to solar energy. The hot water system we focused on was the closed-loop antifreeze system most commonly used in Michigan. Passive solar heating of air spaces involves aspects of optics so some of the optics benchmarks were addressed in the thermodynamics unit.

The electricity unit included such alternative energy systems as photovoltaic cells, fuel cells and batteries that power hybrid and electric plug-in vehicles, which necessitated teaching electrochemistry. Many of these topics as well as some of the topics on optics do not appear in the physics benchmarks, but are essential to understanding these systems. Both units included scientific inquiry benchmarks. In the thermodynamics unit, students designed their own research projects and posted their results on the World Wide Web.

Because these units were part of a thesis project that needed to be completed by the last day of school, the units were not taught at the same point in the sequence that they normally occur. Thermodynamics was the second unit this year and electricity the third. Both normally fall into second semester. The electricity unit does not build from other units, so the sequencing of that was not an issue. The thermodynamics unit is normally preceded by units on work and energy. Care had to be taken to insure that students were given the prerequisite information.

The summer of 2007, before the units were to be taught, was spent researching details of the various alternative energy systems, their physical structure, function of their various components, physics concepts which explain the functions, mathematical descriptions of the physics, and current research that is being carried out to improve the systems. Time was also spent building solar collectors and photovoltaic cells as well as developing labs, demonstrations and activities that incorporate alternative energy or illustrate basic physics or electrochemical concepts needed to fully understand the alternative energy systems. I kept the students' interest in mind throughout. Writing instruments to assess the students' mastery of benchmarks as well as to collect data for evaluating the thesis took up the remainder of the time. Assessment instruments included pretests, post tests, post surveys, student-generated engagement reports, a homework assignment and post lab questions. All assessments can be found in Appendix III.

DESCRIPTION OF ACTIVITIES

Activities for use in the alternative energy units of Thermodynamics and Electricity are part of a high school college prep course in physics and support the Michigan Department of Education's October 2006 benchmarks. Please consult Appendix IA and IB for a list of benchmarks addressed by each activity. There were 12 students in the class the year these activities were piloted.

DESCRIPTION OF THERMODYNAMICS ACTIVITIES

The benchmarks addressed by each activity in the thermodynamics unit can be found in Appendix IA, the lesson plan outline in Appendix IC and commentary on the lesson plan schedule in Appendix ID. The Thermodynamics unit includes some optics concepts, which are reflected in the list of benchmarks. Below is a chronological listing of the major activities.

Date(s) in 2007	Thermodynamics Activity
9/26	Homework Questions to Accompany "Solar Hot Water: A Primer"
9/27 – 10/19	Study Guide
9/28,10/3,10/4	Specific Heat Lab
10/2	Four Articles on Absorbance and Solar Heating
10/2 – 10/8	Absorbance and Emission Lab
10/10	Boiling Water Lab
10/12	Questions to Accompany "Sun Catchers Tuned to Crank Out the Juice"
10/12	Building a Stirling Engine (Extra Credit)
10/12 – 10/16	Payoff Time Homework
10/15	Building Rockets (Tiny Heat Engines)
10/15, 10/16	"How Does It Work?" Follow-Up Questions on Rockets
10/16 – 10/29	Design Your Own Solar Collector Experiment

Table 1 Dates of Thermodynamics Activities

The Study Guide for the Thermodynamics Unit (student version Appendix IIA, teacher key Appendix IIB, commentary Appendix IIC) was divided into five sections: resources, vocabulary, labeled drawings, calculations and research. The students filled in the guide gradually over the course of the unit as the various concepts were encountered. For the vocabulary terms, I sometimes told the students what to write in for the definitions. Other times the students would write them in and then we went over them as a class to be sure they hadn't omitted a key aspect or important distinction. The labeled diagrams received the most emphasis.

Forms for activities other than study guides can be found in appendix IV which contains blank student forms, teacher keys, and complete commentary of how the activity went with suggestions for teachers interested in implementing the activity in their classroom. There are web addresses for the articles and photos for some of the activities.

Solar Hot Water: A Primer (Appendix IVA) is an article available on the World Wide Web put out by the Arizona Solar Center. I used it as an introduction to thermodynamics as it is concise and easy to read, and contains diagrams that illustrate the concepts. Solar hot water systems incorporate a multitude of thermodynamics and optics benchmarks and are currently the most cost effective alternative energy system. Students read the articles and answered questions that emphasized energy conservation and the connection to the climate in Michigan.

In the Specific Heat Lab (Appendix IVB) students tested various liquids to see which is best suited for use in the manifold of a solar collector. The lab provides an opportunity for practice with scientific inquiry skills and addresses the content in qualitative manner.

It also includes mathematical calculations. Students must engage in critical thinking to answer the questions posed in the lab.

The four articles on absorbance and solar heating (Appendix IVC) were to serve as an introduction to the topic, and also to expose students to different types of writing. Two of the articles were written for the general public, one is a journal article and the fourth is a patent abstract. All four were found on the World Wide Web. Web addresses for the articles can be found in appendix IV. Students were asked to skim the articles, highlighting parts they found interesting or felt were important. As a class we discussed those parts.

In the Absorbance and Emission Lab (Appendix IV D) students investigated materials that could work well as absorbers for use in solar space heating. The initial portion of the lab reviews the electromagnetic spectrum and relates the properties of the various wavelengths to their behavior in a room heated by solar radiation. The meat of this section is a very detailed labeled drawing. Questions in the lab guide students through the analytical process of choosing suitable materials to test, as well as eliminating unwanted variables. As this was their first major lab, the analysis and conclusion sections give specific direction as to what the student should include.

Directions for the Boiling Water Lab (Appendix IVE) are so short and simple that they were displayed on the overhead projector. Students heated water on a hotplate, recording the temperature every one minute until the water had been boiling for three minutes. Misconceptions were evident in arguments over whether the water was boiling. Students plotted the data on a line graph. We discussed the meaning of the graph's shape.

The article *Sun Catchers Tuned to Crank out the Juice* (Appendix IV F) describes Stirling engines whose source of heat for the hot reservoir is solar radiation. Reading the article required students to think hard, but answers to the questions were in the text. This article was chosen as an introduction to Stirling engines because it demonstrates that they are currently being developed as a means to generate electricity in the United States.

Building a Stirling Engine (Appendix IV G) was offered as an extra credit option. Students did the project at home and then presented it to the class. The rubric was displayed on the overhead projector and those students that were interested copied it down. Students could receive a majority of the points even if they are not able to get the engine to function. Extra points were awarded if the hot reservoir was heated by solar radiation. Plans are widely available on the Web. (See appendix IV G for several addresses.)

The Payoff Time Homework (Appendix IV H) was an internet-based assignment. Students researched the amount of time it would take for a household in Michigan to pay off the investment incurred for a closed loop antifreeze water heating system and a geothermal heat pump. They also reported any current tax credits available that could be used to shorten the payoff time.

Building Rockets (Tiny Heat Engines) (Appendix IV I) was not an activity that I developed myself, but found in on the Web. (See Appendix IV I for the web address.) The rockets are made out of everyday objects that kids would have at home: aluminum foil, a paper clip, a straight pin and a match. In appendix IV I are some photos I took of the materials and steps in construction. I have also included tips for success and pitfalls to watch out for. If they are built carefully following the tips, about 75% of the rockets perform well. We had a contest outside after each student had made 5 rockets. The rocket that went the longest distance won. Students voiced ideas of changes they would make when they constructed them at home to get them to fly even farther. The ones we made in class flew between 30 and 60 centimeters.

The day after we built rockets we did some follow-up questions on them on a sheet titled *How Does It Work?* (Appendix IV J). To answer the first set of questions students need access to a diagram of a gasoline engine. Most high school physics texts contain one. The second set of questions asks about the rockets. Once students figured out the gasoline engine they could use it as a model of a heat engine to help answer questions about how the rockets work. The discussion of the question sheet consisted of the instructor asking leading questions to get students to logically think their way through, coming up with answers on their own after being guided in the right direction.

Design Your Own Solar Collector Experiment (Appendix IV K) pulled together many of the thermodynamic and optic concepts learned in the unit and gave students another opportunity to practice actually *doing* science. This lab addressed a majority of the science inquiry benchmarks (see Appendix IA). Students drew a flat plate collector and listed everything they could think of that could be varied and tested. We discussed the list as a class, coming up with more ideas and mulling over challenges posed. Students then broke up into groups of three, decided which parameter to vary and began designing their experiment. They were required to fill out a research proposal and discuss the proposal in detail with the instructor. Each group built three collectors, two that were identical and one that varied one parameter, then collected data outdoors. Students wrote up formal lab reports, presented their findings to the class and posted their findings on a website that was developed by one of the students expressly for this purpose.

DESCRIPTION OF ELECTRICITY ACTIVITIES

The benchmarks addressed by each activity in the electricity unit can be found in Appendix IB and the lesson plan outline in Appendix IE. Below is a chronological listing of the major activities.

Date(s) in 2007	Electricity Activity
10/30 – 12/3	Study Guide
11/1, 11/14	Building Circuits Lab
11/7	Electrolysis Lab
11/16	Car Battery Demonstration with Student Question Sheet
11/19	Voltaic Pile Lab
11/20	Building a 3-D Model of a Fuel Cell or Hybrid Car Battery
11/27	Homework Quiz to Accompany Article on Photovoltaics
11/27, 11/28	Building a Photovoltaic Cell Lab
11/28	Photovoltaic Cell Post Lab Questions

Table 2 Dates of Electricity Activities

The unit on electricity also had a Study Guide (student version Appendix IID, teacher's key Appendix IIE, commentary Appendix IIF). It was broken into three sections: vocabulary terms, labeled drawings and math equations. Again, the section on labeled drawings was emphasized. Students filled in parts of the study guide throughout the unit as concepts were encountered. This gave students a complete packet of information to help them prepare for the quiz and unit test. I reminded students that the mathematical concepts should be practiced by actually doing math problems, not by simply studying the equations on the study guide. I suggested they pick out one or two of each type from the text book to do to help prepare for the test.

Forms for the remainder of the activities in the Electricity unit can be found in Appendix V. These include blank student copies, teacher's keys, and comments to help teachers that would like to implement the activities and photographs.

The Building Circuits Lab (Appendix VA) was a fairly open-ended activity. A cart of electrical equipment was wheeled into the room. Students worked in groups of two so that they could all have a chance to manipulate the equipment. They were instructed to accomplish five different tasks which all involved building circuits. The five types were listed on the lab handout with a space for my signature beside each one. Students had to demonstrate for me that the circuit worked and was the type requested. Students who had no prior experience building circuits needed a lot more time. However, this gave the more experienced students time to tinker and build on circuits of their choosing.

Before doing the Electrolysis Lab (Appendix VB), we discussed all of the ways that electricity can be made. Most students knew that a battery transforms chemical energy to electrical energy, but did not know that electrolysis was the opposite transformation. The lab materials led students through the events happening in a battery versus the events happening during electrolysis. The students then built an electrolytic cell using a short length of clear rubber tubing and a jumbo paper clip (my design). Electricity from a 9-volt battery powered the reaction.

Continuing their electrochemistry education in preparation for studying fuel cells and batteries that power hybid and plug-in cars, I performed the Car Battery Demonstration (Appendix VC). Students had a question sheet that they filled in as I did the demonstration. This is best done out in the parking lot and requires a battery that has removable caps. During the demonstration students lifted a car battery (it is very heavy due to the lead plates) and listened to a safety talk. Volunteers took turns getting voltage readings for each of the 6 cells using a multi meter, and specific gravity readings using a hygrometer. They then used a chart in the lab packet to determine the percent charge of each cell. Students made labeled drawings of the workings of the battery and wrote out the half reactions taking place. The final questions in the lab got students thinking about what characteristics would be desirable if the battery were for a hybrid car instead.

The Galvanic Battery Lab: The Voltaic Pile (Appendix VD) is an adaptation of the commonly known lab. Students used pennies and paper towel soaked in salt water to make series and parallel circuits. The lab focused their attention on the basic parts of the galvanic battery – the anode, cathode and electrolyte. Students investigated differences in voltage of various configurations using a multi meter. Differences encountered, along with leading questions in the lab, resulted in critical thinking and teachable moments.

Students were given the opportunity to Build a 3-D Model for Extra Credit (Appendix VE) on their own at home. The model could be of a fuel cell, a battery for a hybrid car, or a battery for an electric plug-in car. The models did not need to be functional. The student was to label all of the components and present the model to the class. The presentation included an explanation of the model, its components and how the battery or fuel cell works. Information on recent advances in the technology and challenges that exist were to be included in the presentation.

To introduce photovoltaic cells, the students were assigned an article to read for homework. The morning after, the students were given the Homework Quiz to Accompany the Photovoltaics Article (Appendix VF). The quiz consisted of three questions about the main ideas in the article: what the letters PV stand for, what happens when sunlight is absorbed by a PV cell, and places these cells can be found. Besides the web address for the article, the quiz questions and the teacher's answer key, Appendix VF also contains a description of my method of giving homework quizzes. (Students roll dice after taking the quiz to determine whether it will be turned in. This cuts down on paper correcting, but also forces the student to focus and do his best on the quiz.)

The homework quiz set the stage for day one of the Building a Photovoltaic Cell Lab which was adapted from a Flinn Scientific kit (Appendix VG). Information for ordering the kit, along with details of the changes I made, is included in Appendix VG. On this first day of the lab students prepared a concentrated hibiscus dye, rinsed, dried and found the conductive sides of the glass plates which would become the electrodes. They also prepared a dilution of nitric acid, made a paste of titanium oxide and coated the anode with a thin coat of that paste. The anodes were stored overnight completely submerged in the dilute nitric acid solution.

On day two of the lab, students dyed the anodes with the pink hibiscus dye, coated the cathode with carbon from a candle flame and assembled the cells. A multi meter was used to test voltage and amperage output of the cells under a variety of conditions.

The day we finished building the photovoltaic cells, students were given an information sheet that comes as part of the Flinn kit. I asked students to copy the labeled diagram and read the information sheet before attempting to answer any of the Photovoltaic Cell Post Lab Questions (Appendix VH). Most of the answers could be given by carefully scrutinizing the diagram.

ASSESSMENT TOOLS

Pretests and post tests were administered for both the Thermodynamics unit (Appendix III A through III D) and the Electricity unit (Appendix III G and III H). Pretests were administered in an informal setting as surveys. Post tests were embedded into the unit tests. Questions correlate to specific benchmarks so that analysis can show whether the unit was effective in teaching the benchmarks. Most of the questions were open ended, requiring a student generated response.

Building a Photovoltaic Cell Post-Lab Questions (Appendix III I) was used as data for the purpose of analyzing student motivation when engaged in hands-on activities, rather than mastery of benchmarks. Data tabulated included number of students that turned the assignment in, scores earned on the assignments, and number of questions that students attempted to answer.

In an effort to quantify student motivation, the students helped gather data on engagement in classroom activities (Thermodynamics Appendix III F, Electricity Appendix III K). At their assigned time, each student looked around the room and recorded the number of students that appeared to be engaged in the activity. The students also recorded the date, time, number of students not engaged and a description of the activity. I looked through these immediately after class, as some students were not very specific when describing the activity. I wrote in a more specific description on some of them while I still remembered what we did during the hour.

At the conclusion of both units, a Post Survey (Thermodynamics Appendix III E, Electricity Appendix III J) based on open-ended questions was administered. I asked students what we did in the unit that really engaged them, what bored them, which things they thought they would remember a long time or make use of in the future. The final question asked them why they thought the particular things they listed would be remembered longer or would be useful. When analyzing these data I tried categorizing the answers many different ways to see if any patterns emerged.

Lastly, Student Grades and Attendance for the Electricity Unit (Appendix III L) were compiled and analyzed to assess motivation and look for mastery of benchmarks. Grades from all of the assignments and assessments for the unit were included.

RESULTS

Following is a brief analysis of the activities and assessments that were developed for this thesis. They were implemented in a high school physics class of 12 students to address thermodynamics, optics and electricity benchmarks and to increase student motivation. Complete teacher comments and reflections on each activity and assessment tool can be found in Appendices II, III, IV, and V. Images in this thesis are presented in color.

ANALYSIS OF HANDS-ON ACTIVITIES

Specific Heat Lab For Solar Collectors (Appendix IVB)

Brainstorming and experimental sections of the lab went very well. There was lots of participation and interest ran high. The students engaged in critical thinking and built on their own knowledge during brainstorming and the class discussion.

Performing the lab procedure went well except that it took longer than expected. I plan to change the lab to test two liquids rather than three. Students had trouble recording data and figuring out the mathematics. For example, they were unsure at what point the aluminum was at its initial and final temperatures. So I spent time with individual groups, guiding them towards figuring out the right answer on their own.

Only two students out of 12 completed the assigned lab packet. One student did not hand the packet in at all. The average packet was 76% complete.

The goal of motivating students was met for most portions of this activity. Students were motivated and engaged in brainstorming, experimental design and performance of the lab. Students demonstrated scientific inquiry skills while performing the lab. Lack of completion of the assigned lab packet made it difficult to assess whether the activity was successful in teaching content benchmarks.

Absorbance and Emission Lab: Heating Solar Spaces (Appendix IVD)

Drawing #2 under the background section, ray diagram of a solar room, was invaluable in helping students understand and answer the questions presented in #3 and #4. When students discussed designs for their experiment, many of them were referring to this drawing. The drawing also laid a good foundation of knowledge for the lab "Design Your Own Solar Collector".

Originally, it seemed that the greatest challenge with data collection would be the time constraint. (The data of most interest is collected while the system is cooling.) But the student-designed solar spaces lost heat so fast that within an hour of shielding them from the sun, their temperatures had dropped to the outside air temperature. Next year students will need to work on better insulation and an absorber that radiates heat more slowly.

One student chose to eliminate the color variation between her clay and rock absorbers by coating the rock in a thin layer of clay.

Figure 1 Eliminating Color Variation

Figure 2 Students Accidentally Block Sun While Collecting Data

The goals set for this activity were partially met. Students were motivated during brainstorming, building the collectors and performing the lab. They were not very motivated to do things that took extra effort at home, like gathering materials to bring in or writing up the lab afterwards. Students demonstrated scientific inquiry skills and their ability to answer the questions and problem solve during the lab indicated that the materials and activities were effective in teaching content.

Boiling Water Lab (Appendix IVE)

Students who believed that water could not be boiling unless the inexpensive classroom thermometer read 100 °C were forced to face their misconception when confronted with water full of bubbles that were rising when the reading was only 99.2°C. Likewise, those who thought that the temperature of a substance always rose when heat was added to it witnessed physical evidence that did not mesh with their beliefs. I could hear students reconfiguring knowledge as they argued with each other about whether the water was boiling and as they voiced frustration that the thermometer was stuck.

Students who did not figure their way through it during the lab, voiced their understanding as we discussed the shape of the graph afterwards. The goal of teaching the concept that heat absorbed during a phase change does not warm the water was met. Students had an easy time understanding the lecture on heats of vaporization and fusion that followed.

Some students were turned off rather than motivated by this activity, expressing that it seemed pointless to stand there and record temperatures. But many of those that stuck with the activity and struggled to make sense of what they were seeing, seemed to appreciate the impact of doing it physically after our discussion.

Building a Stirling Engine (Extra Credit) (Appendix IVG)

Only one student tackled this project. I will continue to offer this one as extra credit, but need to make changes in order to motivate more students to participate.

Figure 3 Student Project

Steam from water boiling inside the pop can was supposed to cause the balloon to inflate and turn the crank which was attached to the balloon, making the CD turn. As the gas in the balloon cools from being exposed to the air around it, the balloon would deflate, again causing the crank to turn. Unfortunately, the student was unable to get a tight seal where the PVC pipe entered the pop can. Too much steam escaped there. The balloon did not inflate.

Figure 4 Close-up of the Crank

The project addressed benchmarks that cut across science disciplines (Appendix IA), and gave the student hands-on experience with science inquiry skills. The students who did not participate benefited from watching the presentation. They seemed focused and interested. The fact that the student was not able to get it to work helped me hammer home a basic truth: persistence and patience are very important attributes in science.

Building Rockets (Tiny Heat Engines) (Appendix IV I)

I will do this activity again. The purpose of building rockets was to catch the students' interest and motivate them to want to learn more about how heat engines work. It generated so much interest that students were very engaged in follow-up questions the next day. They seemed to really want to understand how the rockets worked. The activity itself was not intellectually engaging as students were simply following directions and were totally absorbed in the physical challenge of constructing the rockets. But it was more effective than any of the other labs at motivating students to engage intellectually in the post lab activity.

Design Your Own Solar Collector Experiment (Appendix IV K)

This project brought together most of the concepts and skills students had learned in this unit. The emphasis was on experimental design, but to design a sound experiment and analyze their results, they needed to use science content from the unit. Having the students draw the flat plate collector before asking them what could be varied, was very effective. They came up with a very long list of things to vary and test. Students were physically and intellectually engaged in self-designed scientific inquiry, and were motivated to solve design problems. (They seemed energized by the challenges the problems presented.) Posting their results on the World Wide Web met my goal of having students communicate results of authentic research to the outside world.

A major challenge of this activity is the time involved, 2 full days and 4 half days. It was difficult to meet with all of the groups to go through their proposals even with this small class of 12 students. Also, for this lab to be truly open-ended, I had to provide equipment students would not have readily available at home. This could be prohibitively expensive. And, as with the Absorption and Emission Lab, weather is an issue. Luckily, there is nothing about the lab set-up that is time-sensitive. Once the students have their collectors built, they can be stored until there is a sunny day.

Changes I plan to make next year include finding a web site with more traffic on which to post our results and eliminating the presentations. They were redundant with the web posting. I also need to find a way to streamline the process of meeting with each group.

Building Circuits Lab (Appendix VA)

I had trouble getting around to all of the groups in a timely manner when they needed me. Some students were frustrated needlessly by using bulbs that were burned out. The filaments break if the bulb is dropped.

Students who figured circuits out on their own by manipulating equipment seemed very pleased with themselves. Those who became the most frustrated, seemed to exhibit the most pleasure when they finally figured it out. This activity met the needs of this group where prior knowledge varied considerably. Some students needed a whole class period just to get a bulb to light. Others worked through the required circuits quickly, and then stayed busy with more complicated circuits of their own design.

This activity met the goals of addressing benchmarks of scientific inquiry and electricity. The students were also motivated and worked hard all hour for two periods. I do need to experiment with the task where students compare the brightness of bulbs in a parallel circuit to those in a series circuit as results were opposite of what I had expected.

Electrolysis Lab (Appendix VB)

I had not had much prior experience with batteries and electrolytic cells. That made for a less effective presentation of the material. The goal of teaching electrolysis theory was not adequately met and students confused electrolytic cells with batteries even at the completion of the unit. I need to improve the lab packet and my presentation of background information, leaving out some of the detail so that students can focus on the main ideas.

I was delighted with my own idea for the U-tube apparatus. The reactions were easily visualized. Students had no trouble setting up the apparatus, although some had trouble filling the tubes at first. Students were highly motivated during the lab. I plan to use this lab again next year after making the above-mentioned improvements.

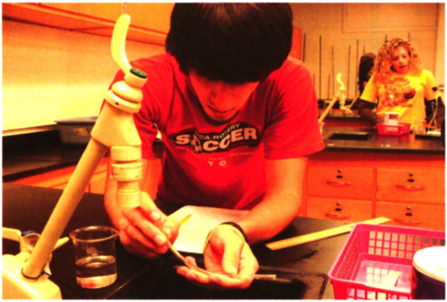


Figure 5 Puzzling Over How to Avoid Bubbles When Filling the U-Tube

Figure 6 Changing from Distilled Water to Electrolyte

Car Battery Demonstration with Student Question Sheet (Appendix VC)

Having access to a car that has the right kind of battery may be the greatest challenge for those who want to do this demonstration. Most of the new car batteries do not have removable caps, so you cannot check the specific gravity. In Appendix VC I describe an alternative way of doing the demonstration if it has to be done in the classroom.

I plan to do this activity again. It met the goal of connecting electrochemical concepts to everyday life. Two students actually checked their own cars to see if the battery had removable caps. All students were motivated to fill out the question sheet, although two of them were turned off by the topic and copied answers from other students rather than thinking it through on their own. Students learned the structure and function of a car battery as evidenced on the unit test.

Galvanic Battery Lab: The Voltaic Pile (Appendix VD)

The apparatus is so simple and easy to set up and rearrange that students had plenty of time to come up with their own little experiments. The goals of the activity were adequately met. Students were engaged physically and intellectually during the procedural part of the lab. Students focused on the main parts of a galvanic battery, seeing how it works, without the clutter of a lot of other details and investigated the behavior of series and parallel circuits. Limiting the group size to two students assured that all students were able to manipulate the equipment.

The activity seemed only to motivate students to think and verbalize their thoughts while they were manipulating the equipment. They did not write much on paper during the lab or to think or write after they were finished manipulating the equipment. I will see if this is the case with a different group of students next year.

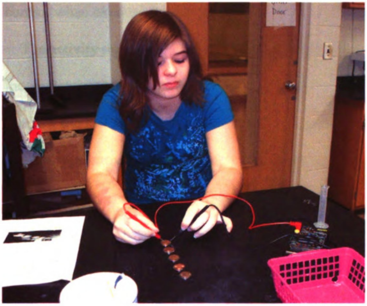


Figure 7 Taking Voltage Readings of Individual Cells

Building a 3-D Model for Extra Credit (Appendix VE)

No students completed the project. Their decision to make the due date four weeks into the future may have resulted in procrastination.

Depending upon the level of initiative in next year's group of students, I may attempt this project again. I would insist they set a closer due date, discuss types of materials they could use to help create interest and get them started, and perhaps give them the option of writing the information rather than presenting orally to the class.

Building a Photovoltaic Cell Lab (Appendix VG)

The lab caught and held the interest of most students. They performed a wide variety of lab techniques. Many showed pride in the outcome and voiced delight as they accomplished each step. Some students had trouble reading carefully and following the directions precisely. All groups succeeded in making cells that emitted voltage and current when exposed to light.

The activity met the goal of motivating students while engaged in the procedure, but incomplete answers to the follow-up questions suggest they were not motivated to find out how the cells work. Thus, the activity was not intellectually engaging and little content was learned. Next year I plan to guide the students through the content.

ANALYSIS OF OTHER ACTIVITIES

Study Guide for Thermodynamics and Optics (Appendices IIA, IIB, and IIC)

Most of the information on alternative energy was not in the textbook. The study guide gave students an accurate resource to which they could refer. It was also an effective platform for uniting thermodynamics and optics benchmarks which were in separate chapters in the text. The labeled diagrams conveyed a large amount of information in a small amount of space and provided a concrete visual to focus on when discussing concepts. Students were motivated to fill the guide in on a daily basis, resulting in more efficient use of review time before the test.

I plan to provide more space for labeled drawings and delete Research (section V) except for section VC Stirling Engines, which could be moved to Labeled Drawings (section III).

Homework Questions to Accompany *Solar Hot Water: A Primer* (Appendix IVA)

My goal was to impress upon students that what they are learning is real life stuff, happening now, right here in Michigan. This seemed to have the desired effect on some of the students.

I plan to use the article and questions again. The questions introduced vocabulary and key concepts about conservation and solar hot water systems. Later, when we were working on related labs, many students applied the knowledge from this article in designing experiments and interpreting results.

To generate more interest in doing the homework, I plan to set the stage better when handing out the assignment by asking questions that should promote curiosity and demystify the topic.

Four Articles on Absorbance and Solar Heating (Appendix IVC)

Some students were overwhelmed. Next year, I plan to have the articles arranged in reverse order, starting with the articles written for the general population. This may motivate more students to read them. The students that were interested and engaged in reading and discussion of the articles were exposed to real world alternative energy applications from several points of view.

Questions to Accompany *Suncatchers Tuned to Crank out the Juice* (Appendix IVF)

The article was not easy reading and required students to think. My goal was to introduce Stirling engine technology and emphasize that research in this field is currently going on in the United States. A majority of the students seemed so disinterested that I will find another way to meet this goal next year.

Payoff Time Homework (Appendix IVH)

The average score on the assignment was 54%. Most students that handed in the assignment did not have evidence from the web to back up their answers. Those that did fulfilled my goals of being motivated, learning content and connecting the content to everyday life. However, the percentage of students in that category was small. Next year I will set aside time to discuss internet search strategies in case poor search skills led to low motivation.

How Does It Work? Follow-up Questions on Rockets (Appendix IVJ)

Focusing on the gasoline engine and tiny rockets gave students two very concrete examples to consider. The students seemed to feel more confident with what hot and cold reservoirs are after using actual examples like hot gas in the cylinder and cooler exhaust. The students were motivated and learned content. I will repeat this activity next year.

Study Guide for the Electricity Unit (Appendix VA)

The act of developing the study guide forced me to look at the unit as a whole and determine which ideas were most important. This provided a framework around which I structured daily lessons and wrote assessments. Calling the packet a study guide, rather than an objective sheet as I had done in the past, drew attention to its importance and resulted in students being more motivated to fill it in on a daily basis.

After completing the unit, I realized several areas that were overlooked. There were no lessons that addressed direct current and alternating current. We did not even fill those terms in on the study guide. And the study guide completely omits the concept of short circuit. This should be included in future versions of both the vocabulary section and the labeled drawings.

Homework Quiz to Accompany the Article on Photovoltaics (Appendix VF)

The goal of motivating students using this article was not met. Half of the students did not read the article. The average score on the quiz was 62%. The goal of introducing photovoltaic cells was met by discussing the answers to the quiz afterwards. I need to think of a question that I could ask as I pass out the article that will pique their interest.

Building a Photovoltaic Cell: Post Lab Questions (Appendix VH)

Students did not do well on the assignment. The lack of effort may indicate that although the students enjoyed the physical task of building the cells, it did not result in a desire to understand how they work. Content was addressed when we went over the questions after I handed the assignment back, but most students did not work through understanding it on their own. Next year I plan to spend time discussing the labeled drawing on Flinn's information sheet, guiding students through constructing knowledge before sending them home to do the assignment.

ASSESSMENT TOOLS

Thermodynamics Pretest and Post Test : Item Analysis (Appendices IIIA, IIIB, IIIC and IIID)

Because most of the questions were open-ended and required a student generated written response, the scoring was quite subjective. I scored both the pretest and the post test twice. The second scoring occurred about eight weeks after the first. The second time I wrote out a simple rubric beside each question and followed it closely. As the first scoring was done without a rubric, only the data from the second scoring is used in the analysis below.

Looking at the scores from the pretest and the Unit 2 Test (post test) and noting the t-test results, allows conclusions to be drawn as summarized in Table 3 below. (Raw data can be viewed in Appendix III C and a more detailed analysis is in Appendix III D.)

Benchmark Topic	Average Prior Knowledge Percentage	Average Post Test Percentage	t-Test Results (Multiple t-tests are due to multiple questions.) * = significant
Energy Transfer or Transformation	25% 27% 26%	48% 48% 48%	0.010* 0.036* 0.019*
	12% 11% 24% 12%	47% 47% 47% 47%	0.002* 0.011* 0.049* 0.002*
	53%	59%	0.653
	53%	59%	0.653
	69%	40%	0.290
	25%	36%	0.741
	25%	38%	0.175
	8%	31%	0.002*
Average	28%	46%	

Table 3 Summary of Thermodynamics Scores by Benchmark

Devices That Transform Energy	32%	31%	0.763
Energy Conservation	9%	76%	0.001*
Calculating Final Temperatures of Two Liquids	0%	70%	0.000*
	0%	92%	0.000*
	19%	67%	0.002*
Average	6%	76%	
Ray Diagrams	30%	50%	0.309
	30%	20%	0.824
Average	30%	35%	
Scientific Inquiry	58%	92%	0.048*
	54%	81%	0.043*
	37%	86%	0.014*
Average	50%	86%	

Table 3 Continued

Scores earned by individual students for each pretest and post test question were entered into a t-test formula to calculate p values (probability that the change is due to chance). P values less than 0.05 were considered significant. Degree of freedom for these tests was 11. As indicated by the asterisks in Table 3 above, significant gains in knowledge occurred for energy transfer and transformation, energy conservation, calculating final temperatures of two liquids and scientific inquiry. Improvements in the unit need to be made to increase gains in knowledge for ray diagrams and naming devices that transform energy. Portions of the unit addressing energy transfer and transformation also require attention as some of the questions on that topic showed insignificant gains.

The overall low scores on post test questions may be due to a couple of reasons. One, as mentioned in the demographics section, this group of students received relatively low grades in math and science in past years, and they have displayed poor work habits this year. Also, several concepts that the benchmarks assume students learned in chemistry showed close to zero for prior knowledge: specific heat, thermal equilibrium, and the distinction between heat and temperature. Thus the students began the unit with multiple handicaps.

Electricity Pretest and Post Test: Item Analysis (Appendices III G and III H)

Scores entered into the t-tests were based on a ratio of correct responses to total responses as the questions were open ended and students could volunteer multiple responses. For example, question 3 asked students to name devices that transform mechanical energy to electrical energy. If the student responded with generator, wind turbine and pulley, he earned as score of 2/3 or 0.67 as 2 of the 3 responses were correct. Categorizing the test questions by benchmark as shown in Table 4, allows conclusions to be drawn.

Benchmark Topic Addressed by the Question	Question Number	Average Ratio of Correct Responses to Total Responses	Average Ratio of Correct Responses To Total Responses	t-Test p Values
Devices That Transform Energy	1	0.50	0.82	0.152
	2	0.45	0.95	0.008*
	3	0.50	0.64	0.493
Average		0.48	0.80	
Open and Closed Circuits	4	0.55	1.00	0.016*
	5	0.91	1.00	0.341
	6	0.82	1.00	0.167
Average		0.76	1.00	
Voltage	7a	0.00	0.82	0.000*
Resistance	7b	0.59	0.86	0.52
Current	7c	0.77	0.91	0.082
Electrochemistry	8a	0.82	2.2	0.000*
	8b	0.45	1.64	0.173
Average		0.64	1.92	
Series and Parallel Circuits	9a	0.64	0.73	0.666
	9b	0.09	0.27	0.291
	10a	0.82	0.91	0.557
	10b	0.27	0.27	1.000
Average		0.455	0.545	

Table 4 Summary of Electricity Scores by Benchmark

Scores earned by individual students for each pretest and post test question were entered into a t-test formula to calculate p values (probability that the change is due to chance). P values less than 0.05 were considered significant. Degree of freedom for these tests was 11. As indicated by the asterisks in Table 3 above, significant gains in knowledge occurred for the topic of voltage as well as for one of the questions under devices that transfer energy, closed and open circuits and electrochemistry. Improvements in the unit need to be made to increase gains in knowledge for resistance, current, and series and parallel circuits. Portions of the unit addressing devices that transform energy, open and closed circuits, and electrochemistry also require attention as some of the questions on that topic showed insignificant gains. For questions with two parts, part b asked students to explain their answer or drawing from part a. Scores for explanations were much lower than scores for answering part a.

Building a Photovoltaic Cell: Post Lab Questions (Appendix III I)

Scores were low indicating low motivation. Of the ten students that turned the assignment in, only four of them attempted to answer all 12 questions. Many answers that were given displayed a lack of understanding. There is a chance that some of the students did their best on the assignment, but are not able to read carefully or make sense of what they read.

Thermodynamics Post Survey (Appendix III E)

Raw data and a complete analysis of the data as well as a critique of the methodology can be found in Appendix III E. Some examples of student responses are as follows. "I like making things", "because we were up and moving", "learning how many different variables there are when building", and "Would rather learn hands-on". The most comments about what students found boring referred to the articles: "Quite dull", "Didn't help my understanding of thermodynamics", "tedious", "It was early in the morning and hard to focus on reading". Responses to the question asking what they are likely to remember a long time or make use of included how a solar collector works ("the structure of a plate collector" and "how an absorber plate and manifolds affect the overall performance"), how to make a rocket, how to make my house more energy efficient, heating and solar energy, how a geothermal pump works ("hot and cold reservoir"), not a whole lot ("because what I am going to do has nothing to do with this"), how people use alternative energy and how many resources and money alternative energy saves. The last question asked why those items would be the ones they will remember the longest or make most use of. Student responses mentioned the words fun, creative, real life problems, sweet, and hands-on

It appears that hands-on activities are more engaging regardless of the topic. The topic seems to make a slight difference. A little more than half of the positive responses related to the topic of alternative energy and a little less than half of the negative responses related to the topic. Whether or not the student judges the information to be useful, seems to carry as much weight as whether they found the information interesting or fun.

Category	Most Common Responses
Engaging	Labs, especially "Design Your Own Solar Collector Experiment"
Boring	Reading articles, Math, Homework
Memorable or Useful	How things work, How to make things
Why They are Memorable or Useful	Useful, Interesting, Fun

Table 5 Summary of Student Responses to Thermodynamics Post Survey

Electricity Post Survey (Appendix III J)

Raw data and a complete analysis of the data as well as a critique of the methodology can be found in Appendix III J. Examples of student responses are as follows. Talking about labs in general being engaging, students wrote "I tend to learn better and follow directions better if I have things to look at and work with. Book working is sometimes confusing and harder to understand" and "It helps me most if I can see what is going on". Students that listed notes as boring gave these responses, "It helped in the long run, but it was still boring", "I don't mind notes, but there was a lot. I used up half of my notebook" and "Some seemed repetitious and long". When asked what they were likely to remember a long time or make use of students listed, among other things, how a battery works ("and how to draw one"), fuel cell, circuits ("how they work", "circuit building", "schematic symbols and how to use them to make a drawing" and "how series and parallel circuits work and which to use in a certain situation"), energy efficient cars ("I'll probably get a hybrid when I'm older"), resistance ("longer wires makes more resistance than shorter wire"). When asked why those things are the most memorable or useful students explanations included the words interesting, environmental technology, physical, useful, everyday life, and simple. Some comments offering more insight were "something I find interesting is easier to remember than something boring", "the fuel cell is going to be the next greatest thing to stop global climate change and reduce emissions", "I could see and touch them and observe how things worked" and "Because I will always use batteries. They are important things in my life, we use them practically everywhere".

The students found hands-on activities the most engaging, with building circuits the most popular of all. Eighty nine percent of the responses had to do with practical topics (applied science) rather than academics (pure science). Topics listed as most engaging also favored ones that required relatively little mental effort by a ratio of 13 to 5. There seems to be a negative correlation between alternative energy and the degree to which the activity engaged students.

When asked what they would remember a long time or make use of, 88% of the responses had to do with practical things, most with how things work. Students felt that the reasons they would remember or make use of these were because they were interesting, useful or related to their daily life.

Category	Most Common Responses
Engaging	Building circuits and Labs in general
Boring	Notes, Math, Voltaic Pile Lab
Memorable or Useful	How a battery works, Fuel cells, Circuits
Why They are Memorable or Useful	Interesting, Useful, Everyday Life

Table 6 Summary of Student Responses to Electricity Post Survey

<u>Student Grades and Attendance</u> (Appendix III L)

Disregarding scores of zero, the only tasks where the class average was above 77% were the two tasks that were graded on completion rather than accuracy. As a group, students whose grades did not reflect mastery (lower than 80%), had grades at least 35% lower that the group that exhibited mastery, again disregarding those who earned a score of zero. Note that n = 11 for this data.

Attendance can be an indicator of interest and motivation. Other than the student that dropped the class, no student had more than 2 absences during this unit.

Data Collected By Students: Student Engagement Data (Appendices III F and III K)

According to the students' data, hands-on activities are more engaging than those that are not hands-on. Twice as many students were off task when the activity was not hands-on. Whether the activity involved alternative energy did not affect engagement.

These data were found to be unreliable. There were multiple instances of a student's data not matching up with the number of students that were in the class that day. A student reported 8 students on task and 4 off task when there were only 11 students present. And all too often most of the day's data turned in showed that 100% of the students were on task most of the hour. Looking out over the class from my vantage point, that was hardly ever the case. The only times I would say that it was true were the days the students were physically building, like the days we built rockets or solar collectors.

The students did not have the skills necessary to gather and record the data in an accurate manner. However, the relationships indicted by their data agree with data from the unit post surveys and from my notebook of anecdotal commentary. The raw data, compiled data, analysis of the data and critique of this method of collecting data are all included in appendices III F and III K.

DISCUSSION AND CONCLUSION
STUDENT MOTIVATION

What moves the student to act or to engage themselves deeply enough in the task at hand that substantial learning takes place? This thesis began as an attempt to remedy the student apathy, boredom and underachievement that has become the norm at Owosso High School. The class of 12 physics students was reflective of this observation. As a class, their grades in previous years' math and chemistry courses averaged out to a B. Before beginning the physics course, some students had completed algebra 2, others only geometry. The more vocal students bragged about how little effort they put forth in the past and plan to put forth in the future.

The hypothesis of this thesis was based on the expectation that students would be motivated, engaged and turned on to physics and science in general by becoming involved in hands-on activities and authentic research centering around a relevant topic, alternative energy. The physics units that support this topic most effectively are thermodynamics and electricity.

Students showed the expected lack of motivation on day two of the research by failing to look up information needed for the next day's activity. This behavior contrasts with the next day when they jumped right into the hands-on lab work. Lots of physical effort was expended in constructing collectors. They also put forth mental effort during the whole-class and small group discussions, thinking critically about the various characteristics this liquid should possess.

The lab write-ups were very poorly done. Only two students out of 12 completed the whole packet. One student did not hand the packet in at all. On average, students completed only 76% of the packet. Seven of the eleven students wrote nothing under analysis and conclusion.

Students displayed the same pattern of behavior throughout the thermodynamics and electricity units. Some students would usually engage in critical thinking during class discussions, but many of their thoughts would not get recorded. Almost all of the students were engaged during the hands-on portion of the labs, some motivated enough to think critically while performing the lab. But most put minimal effort into the lab write-up, both the parts done during the lab such as observational questions and collecting data, as well as the portions written afterwards like the analysis and conclusion. During the activity "Design Your Own Solar Collector Experiment", a majority of the students were excited and had lively discussions during the planning phases of their research proposals. However, very little of their plans were written down on the proposal form. Most students wrote down the bare minimum, leaving out important details like what the absorber would be made of or how they would collect temperature data (which was an important challenge in most of their set-ups).

Lack of motivation was also apparent in any work that needed to be done outside of class. It did not seem to matter whether it had to do with alternative energy or whether it was hands-on or related to authentic research. For the "Design Your Own Solar Collector Experiment", only one student brought the materials on the day I had scheduled to start the lab. They next day they finally all brought materials.

Only one student made the Stirling engine at home for extra credit, and none made the model of a fuel cell or hybrid car battery. Half of the students did not hand the Payoff Time assignment in at all. An article on photovoltaics was assigned as a homework reading prior to the class building photovoltaic cells. The fact that there would be a short quiz over the material in the article was not enough motivation to get students to read it. From the answers they gave, it was obvious that no more than half of the students had read it.

This group of students did not seem to be motivated much by grades. The three students that got good grades, got good grades consistently, regardless of whether the topic had to do with alternative energy and whether or not it was a hands-on activity.

According to the surveys given at the end of each unit (see Appendices III E and III J), the activities that students listed as boring were things that are not hands-on regardless of whether they had to do with alternative energy. Conversely, when asked what they were likely to remember a long time or make use of later, most of the items listed had to do with alternative energy.

When asked why they felt those things were the ones that ended up on the list of things they would remember or make use of, three categories of explanations stand out. They are "interesting", "useful" and "relates to my everyday life". It would seem then that these three would be chief motivators. The data didn't show that to be the case.

On the positive side, students put forth a lot of effort during the physical part of all the hands-on activities. They were focused and stayed busy. The only lab this focus did not hold true for was the boiling water lab which is mostly just waiting and recording temperatures.

Their level of motivation held for the rest of the hands-on activities whether they had to do with alternative energy or not. They enjoyed putting equipment together, manipulating it, observing what happened and taking things apart. Most of their conversation during the physical part of the labs was about the lab itself. Their interest seemed genuine and quite often students asked to stay after the bell to finish up if they ran out of time.

In summary, hands-on activities, regardless of the topic, motivated these students. However, the motivation resulted in increased effort during the physical part of the hands-on activity only. Motivation was still low for any prelab or post lab activity even when the students were absolutely fascinated with the topic during the physical part of the lab. Class discussion was one exception. In general, students threw themselves into class discussions, coming up with insightful points and piggy backing off of each other's ideas.

How can we get the fascination to carry over to the point where students want to find out why or how the lab works so much that they will be willing to put forth the mental effort to figure it out and willing to do work of looking things up on the internet or writing things down on paper? *And why does it seem to require so much effort to think critically, collect ones thoughts and write the thoughts on paper or to physically do a task like research a topic online or gather some materials?* Psychologist Mel Levine (2002) feels that it does take a lot more effort for some people to do this than others. I think perhaps a good analogy is how it takes a lot of effort for some people to be cheerful and alert in the morning. It may be just the way their brain is wired. But it does seem that there are more students in this category than there should be.

For my physics students, it took a lot less effort, so less motivation was needed, to get them engaged in discussions requiring critical thinking compared to getting them engaged in written assignments. Perhaps a remedy would be to use the discussion format as a stepping stone toward writing one's thoughts on paper.

STUDENT ENGAGEMENT

Key to evaluating the level of student engagement, is the agreement upon a definition. Webster's dictionary says to draw into, to involve; to attract and hold (the attention); to employ or keep busy; occupy. Looking at the definition from an educational theory perspective, Chester E. Flinn in Education Next (2006) talks about "sleeves rolled-up engagement," whereas David Zyngier (2007) of Monash University in Australia speaks of "actively engaging their intelligence."

In retrospect, before enlisting my students to gather data on engagement, we should have discussed which type of engagement was of interest in this master's thesis study. Or we could have made a distinction between physical engagement and intellectual engagement. Physical engagement is certainly better than no engagement at all. But it's very important to realize that the ultimate goal in an educational setting is intellectual engagement (Crawford 2000, Darby 2007, McDermott, 1993). It may be that only the teacher has had enough training to tell the difference.

There are numerous descriptors of signs of intellectual engagement in the literature. For example, James Kushman (2007) of Waldo Middle School in Salem, Oregon relates, "Students talk about their projects a lot – even in relation to things they see and hear outside of school." Linda Darby (2007) from the University of Ballarat discusses what should happen in the classroom. She aptly describes more aspects of intellectual engagement. "...focus(ing) attention and powers of observation, *doing* something with the results...clarifying their understanding...access(ing) old knowledge and transact(ing) it with the new knowledge." Barbara Crawford (2000) from Pennsylvania State University tells what she observed in a room full of engaged high school ecology students. She described their state as one of "intense involvement". "Although no bell had rung the ... students were already involved in their work." Examples she listed that could be classified as intellectual engagement are as follows: "...recording in notebooks, discussing observations with other students, eagerly explaining their projects to a guest and voluntarily searching through books to find an answer to a question the guest had about the project."

In my own physics classroom this year, I have witnessed behaviors that could be classified as intellectual engagement. Students had an intense discussion about whether or not it was possible to vary only the composition of the absorber while keeping surface area and mass constant. It seems that whenever we were brainstorming as a class, at least half of the students were intellectually engaged, volunteering ideas and discussing others' ideas. During the brainstorming session before performing the specific heat lab, students came up with a long list of characteristics that would be desirable for the liquid in the manifold of a solar collector. One student came up with ideas that I hadn't thought of so I added them to my key: that it be inexpensive and readily available.

Some days, when there was time to work on math problems in class, I would hear some students having heated arguments about whose method, or answer, was correct. During tests and quizzes students were intellectually engaged. They stayed focused and thought hard.

I have always been curious about exactly what happens at the smallest physical scale when wavelengths are transmitted, reflected or absorbed. I researched it this past summer and gave a 35-minute lecture to my students with labeled diagrams. Their eyes were bright. I could see the wheels turning. They took notes and asked questions for the whole 35 minutes. Not a single person complained about the length of the notes. It was brand new material for all of them, but it built well on top of their previous knowledge of the electromagnetic spectrum and the macroscopic views of the three processes. This lecture grabbed their interest and resulted in intellectual engagement as evidenced by their insightful questions and comments during the lecture.

During the hands-on portions of the labs, there is always the possibility that students are engaged physically only. This was often true for these two units. But conversations I overheard, questions I was asked or actions I saw some students take, indicated that there were times when intellectual engagement had indeed been achieved. One student used clay to coat the outside of the objects she was using as an absorber so that the color would be held constant. Another spent a good 15 minutes making braces under the manifolds during her solar collector experiment. She had noticed that the plastic hosing drooped down at either end, while the copper tubing was always the same distance from the absorber. She aimed to eliminate that variable.

Multiple times, while building apparatus, students would argue over why something wasn't going to work or why it should be built a different way. Sometimes a student would look back through his notes to labeled drawings we had done together, and then use the drawings to guide his group in coming to a decision

A lot of the time spent in hands-on portions of labs, was time when students were physically engaged, but not intellectually. While building photovoltaic cells, some weren't even reading the instructions carefully. It seemed they wanted to use their hands to create, but didn't want to involve their minds. One student ground up the hibiscus petals rather than titanium oxide in the mortar and pestle. One group used a pipette that had no graduated markings to "measure" out one milliliter of nitric acid. Some students designate themselves as the equipment manipulator. You can hear them say things like, "I don't want to read it. You just read it and tell me what to do." When I asked a student why they got the result they did, she said, "I have no clue. I was just operating the multi meter."

There were also times when students were neither intellectually nor physically engaged. Data from activities, assessments and observations I recorded in the notebook of anecdotal commentary, show that activities most often resulting in disengagement were going over the previous day's homework, watching videos and silent reading.

In summary, there is a difference between physical engagement and intellectual engagement. Intellectual engagement is the ultimate goal and harder to achieve than physical engagement. Activities that proved most apt to result in intellectual engagement were class discussions and labs where students had to design the procedure and equipment or had to make decisions or interpret observations in order to move on to the next step. Tests and quizzes also result in intellectual engagement.

MASTERY OF BENCHMARKS

For the thermodynamics unit, although there were gains in most categories, most students were still not exhibiting mastery (80% or greater). However, it is noteworthy that these students started with very low prior knowledge scores and have a history of low or mediocre performance on average.

According to the percentage gained (Table 3), the unit was most effective at teaching how to calculate final temperatures of two liquids. The average pretest score for this benchmark was 6% compared to an average post test score of 76%. Note though, that students had very little prior knowledge in this area. Energy conservation showed the second highest gain (Table 3) with an average pretest score of 9% and average post test score of 76%. However, those data are based on responses to only one question which addressed two benchmarks.

The unit was effective in teaching energy transfer and transformation, energy conservation, calculating the final temperatures of two liquids and scientific inquiry. Improvements are needed to raise scores for naming devices that transform energy, ray diagrams and also energy transfer and transformation as gains on some questions addressing this benchmark were not statistically significant. Note that the students' *understanding* of how the devices worked increased dramatically from a baseline of zero, but the benchmarks only ask that students be able to name them.

The electricity unit does not appear to be as effective as the thermodynamics unit for the benchmarks measured. Results show students had greater prior knowledge of electricity than thermodynamics. Improvements in electricity scores were less than 65%

for all topics except voltage. Statistically significant gains (Table 4) were seen only for scores on voltage and devices that transform light energy to electrical energy.

For both thermodynamics and electricity, the concepts I taught went much deeper than the state benchmarks. That is not reflected in the data above as the data were analyzed only for increases in knowledge specified by the benchmarks.

POSSIBLE FOLLOW-UP STUDIES

Following is a sampling of questions that could frame follow-up studies.

Quality of Engagement

If higher order thinking is an essential component of quality engagement, how would a researcher determine objectively whether it was occurring?

Small Data Set

The data for this thesis were taken from a very small class of physics students, 13 at the beginning of the first unit and 12 by the beginning of the second unit; a large percentage of these were not high achievers. If this study was repeated with a much larger number of students would the results be different?

Hands-On

The data from this study indicate that whether or not the activity is hands-on plays a larger role in determining the level of motivation than does the topic. If the goal is intellectual engagement, which types of hands-on activities lead to that type of engagement and which do not? This study would necessitate development of a method for identifying and quantifying intellectual engagement.

Variety of Pedagogical Methods

Aside from the notion that different students learn in different ways, for the single student is it better to use a variety of methods rather than all one type? Is there one method that may be better for mathematically oriented concepts while another is better for qualitative types. And/or is variety of methods a way of keeping the students' interest and avoiding intellectual fatigue or apathy?

Labeled Drawings

There are two studies that could be done in this area. First, are graphical representations and labeled drawings more effective than sentences of lecture notes? Secondly, what pedagogical method works well to get students to create these visual pictographs on their own? I expect that the cognitive act of creating them helps make connections in the brain between that material and prior knowledge and also to real life applications.

Interest, Motivation and Attitude

In my teaching experience it seems that as a group, students' interest, motivation and attitudes are deteriorating year by year . A study attempting to find whether this is actually the case, and if so investigation of the cause would be very valuable. If we do not figure out and work on the cause of the problem, our efforts to design quality curriculum and pedagogical methods will be in vain.

More Like College

Would students have greater interest and put forth more effort if high school were more like college, or if they entered college after two years of high school? Many teachers have lowered the rigor of courses to match the low motivation of the students. If students don't do homework, some teachers quit assigning homework. If students don't study for tests, some teachers begin giving tests that students can pass without studying. The rigor in many science courses has dropped to that of the elementary school level. This could cause a vicious cycle of apathy and boredom. Would we recapture the interest of students if we raise standards and teach things that delve deeper into details and require more higher order thinking?

PROPOSED CHANGES IN THE UNITS

Additions Needed to Meet Benchmarks

Looking back over the benchmarks after completing the units, there are some benchmarks that the units failed to cover. The units are already lengthy, and there are very few activities I plan to delete, so it will take some creativity to insert the missing benchmarks into the unit in a way that is meaningful and yet takes up little class time.

The following benchmarks need to be included in the electricity unit in future years:

P3.7B: Explaining why acquiring a large excess static charge (e.g. pulling off a wool cap, touching a Van de Graff generator, combing) affects your hair. This is not in the formal lesson plans, but I did end up explaining it this year.

P3.7d: Identify examples of induced static charges. This could just be included as a question in a homework assignment and reinforced by asking it again on the homework quiz the next day.

P3.7e: Explain why an attractive force results from bringing a charged object near a neutral object. On one of their homework quizzes I ask them to draw what happens when these two are brought together. The question should go on to ask *why* it happens.

P3.7f: Determine the new electric force in charged objects after they touch and are then separated.

P4.10A: Explain how circuit breakers and fuses protect household appliances. This was covered in my previous electricity unit in a set of notes which included a labeled drawing. I also showed how a thermostat works at the same time. Those notes need to be added back into this new unit, after the students have built circuits, as some of them notice how hot the batteries and wires get.

P4.10i: Compare the energy used in one day by common household appliances. Students should have their own copy of the Consumer's Energy pamphlet, or searched online, and made a bar graph to visually represent the comparisons. This could be given as a homework assignment to same class time.

P4.10j: Explain the difference between electric power and electric energy as used in bills from an electric company. The students learn and use the equations for P = VI and E = Pt and we do a sample calculation of energy cost when introducing the kilowatt hour. But having students use their own household's energy bill in some assignment or activity would definitely help tie the lesson to their everyday life. Perhaps calculating how many times they would have to forego taking a hot shower or how many lights would have to be turned off for a certain number of hours would emphasize which appliances really use the bulk of the energy. It would also help illustrate why converting a water heating system to solar would have a greater impact than spending the same amount of money on photovoltaics to run your lights.

A thermodynamics benchmark that could not be covered in this chapter is P4.11a: Calculate the energy lost to surroundings when water in a home water heater is heated from room temperature to the temperature necessary to use in a dishwasher, given the efficiency of a home hot water heater. The students aren't introduced to efficiency calculations until the unit on work. So the benchmark needs to be added to that unit. Optics benchmarks not covered in the thermodynamics unit can be, and were, included in a unit later in the year called "Waves".

Changes That Will be Made Based on the Data

Extra guidance may be needed during hands-on activities to help insure that students become intellectually engaged. I plan to focus on asking leading questions as I circulate among the groups next year. As an example, during the specific heat lab I could say, "I see your aluminum sample is sticking up above the surface of the water. Why would it be better to have it totally immersed?" Or during the Voltaic Pile Lab I could ask, "How could the size and shape of the paper towel (which is soaked in electrolyte) affect the circuit?"

However, the data also show that student motivation for doing post lab activities was highest for Building Rockets which was designed to have students focus on physical engagement during the lab. The intellectual engagement was saved for follow-up the next day. I plan to change both the Electrolysis Lab and the Building a Photovoltaic Cell Lab to that format and compare motivation results with that of the other labs.

Student motivation was very low for homework assignments of all types. I will try to spark interest in each of the assignments asking a question that will pique their curiosity and also by telling some story or interesting news item about the topic of the assignment as I hand it out. For example, when describing the Payoff Time assignment, I could tell the story about my father wanting to install a geothermal system. His friends told him that at it would not pay for itself while he was still alive. He is 72. I could ask students to try to find out for me whether his friends were right.

Most activities in the electricity unit need improvement as only two benchmarks showed significant gains. The extra guidance during hands-on activities may help here as well as rewriting some of the lab materials, especially the electrolysis lab. Students were confused about batteries and electrolytic cells after doing the lab. I plan to remove much of the electrochemistry detail from the lab packet and use it as a follow-up activity.

I may not attempt the extra credit activity Building a 3-D Model next year as there was not interest in it this year. And I may eliminate the assigned articles as we will have less time next year (due to shortened hours) and few students were motivated to read them. They could be offered as enrichment or extra credit instead.

After spending the year developing the units, teaching the pilot classes and engaging in extended analysis and reflection, I am looking forward to the second year. The units were effective at teaching many of the benchmarks according to scores on the pretests and post tests. A majority of the activities resulted in high motivation and intellectual engagement during the physical portion of the activity and class discussion before and after. I am eager to make changes that I expect will carry that motivation and intellectual engagement through the post lab activities. This would result in higher gains in knowledge of the benchmarks. The students have been introduced to a real life application of physics and for some, it sparked a lasting interest. I expect gains in student knowledge to improve every year as I make changes, get more familiar with the content and become more polished in the delivery.

APPENDIX I BENCHMARKS AND LESSON PLANS

APPENDIX I A
THERMODYNAMICS AND OPTICS UNIT
MICHIGAN BENCHMARKS COVERED

The benchmarks referred to are found in the Michigan High School Science Content Expectations for Physics published by the Michigan Department of Education in October of 2006.

Specific Heat Lab for Solar Collectors

P1.1C – Conduct scientific investigations using appropriate tools and techniques.

P1.1D – Identify patterns in data and relate them to theoretical models.

P1.1E – Describe a reason for a given conclusion using evidence from an investigation.

P1.2g – Identify scientific trade-offs in design decisions and choose among alternative solutions.

P4.9B – Explain how various materials reflect, absorb or transmit light in different ways.

Absorbance and Emission Lab for Passive Solar Heating

P1.1C – Conduct scientific investigations using appropriate tools and techniques.

P1.1D – Identify patterns in data and relate them to theoretical models.

P1.1E – Describe a reason for a given conclusion using evidence from an investigation.

P1.2j – Apply science principles or data to anticipate effects of technological design decisions.

P4.9B – Explain how various materials reflect, absorb or transmit light in different ways.

P4.6A – Identify the different regions on the electromagnetic spectrum and compare them in terms of wave length , frequency and energy.

P4.8A – Draw ray diagrams to indicate how light reflects off objects or refracts into transparent media.

P4.8B – Predict the path of reflected light from flat (curved or rough) surfaces.

P4.6h – Explain the relationship between the frequency of an electromagnetic wave and its technological uses.

P4.1B – Explain instances of energy transfer by waves.

P4.5A – Identify everyday examples of energy transfer by waves and their sources.

<u>Design Your Own Solar Collector Experiment</u>

P1.1A – Generate new questions that can be investigated in the laboratory or field.

P1.1B – Evaluate the uncertainties or validity of scientific conclusions using an understanding of sources of measurement error, the challenges of controlling variable, accuracy of data analysis, logic of argument, logic of experimental design, and/or the dependence on underlying assumptions.

P1.1C – Conduct scientific investigations using appropriate tools and techniques.

P1.1E – Describe a reason for a given conclusion using evidence from an investigation.

P1.1f – Predict what would happen if the variables, methods or timing of an investigation were changed.

P1.1g – Based on empirical evidence, explain and critique the reasoning used to draw a scientific conclusion or explanation.

P1.1h – Design and conduct a systematic scientific investigation that tests a hypothesis. Draw conclusions from data presented in charts or tables.

P1.2A – Critique whether or not specific questions can be answered through scientific investigations.

P1.2D – Evaluate scientific tradeoffs in design decisions and choose among alternative solutions.

P1.2g – Identify scientific trade-offs in design decisions and choose among alternative solutions.

P1.2j – Apply science principles or data to anticipate effects of technological design decisions.

P4.1B – Explain instances of energy transfer by waves and objects in everyday activities.

Study Guide

P4.1A – Account for and represent energy into and out of systems using energy transfer diagrams. (Solar hot water system.)

P4.1B – Explain instances of energy transfer by waves and objects in everyday activities.

P4.2A – Account for and represent energy transfer and transformation in complex processes.

P4.2B – Name devices that transform specific types of energy into other types.

P4.2C – Explain how energy in conserved in common systems.

P4.2f – Identify and label the energy inputs, transformations and outputs using qualitative or quantitative representations in simple technological systems to show energy conservation.

P4.5A – Identify everyday examples of energy transfer by waves and their sources.

P4.6A – Identify the different regions in the electromagnetic spectrum and compare them in terms of wavelength, frequency and energy.

P4.6h – Explain the relationship between the frequency of an electromagnetic wave and its technological uses.

P4.8A – Draw ray diagrams to indicate how light reflects off objects or refracts into transparent media.

P4.8B – Predict the path of reflected light from flat, curved or rough surfaces.

P4.11b – Calculate the final temperature of two liquids (same or different materials) at the same or different temperatures and masses that are combined.

Boiling Water Lab

P1.1D – Identify patterns in data and relate them to theoretical models.

P1.1E – Describe a reason for a given conclusion using evidence from an investigation.

P4.2A – Account for and represent energy transfer and transformation in complex processes.

P4.3A – Identify the form of energy in given situations.

Payoff Time Homework

P1.1E – Describe a reason for a given conclusion using evidence from an investigation.

P1.2B – Identify and critique arguments about personal or societal issues based on scientific evidence.

P1.2c – Develop an understanding of a scientific concept by accessing information from multiple sources. Evaluate the scientific accuracy and significance of the information.

P1.2g – Identify scientific tradeoffs in design decisions and choose among alternate solutions.

"How Does It Work?" (Heat Engines)

P3.1A – Identify the forces acting between objects in direct contact or at a distance.

P3.1d – Identify the basic forces in everyday interactions.

P3.2B – Compare work done in different situations.

P4.1C – Explain why work has a more precise meaning than the meaning of work in everyday language.

P4.2C – Explain how energy is conserved in common systems.

P4.2D – Explain why all the stored energy in gasoline does not transform to mechanical energy of a vehicle.

P4.2f – Identify and label the energy inputs, transformations and representations in simple technological to show energy conservation.

Questions on Stirling Engines

P1.2g – Identify scientific tradeoffs in design decisions and choose among alternative solutions.

P3.1c – Provide examples that illustrate the importance of the electric (electromagnetic) force in everyday life.

P4.2B – Name devices that transform specific types of energy into other types.

P4.5A – Identify everyday examples of energy transfer by waves and their sources.

<u>Homework Questions to Accompany "Solar Hot Water: A Primer"</u>

P1.2g – Identify scientific tradeoffs in design decisions and choose among alternative solutions.

P4.1B – Explain instances of energy transfer by waves and by objects in everyday activities.

P4.2A – Account for and represent energy transfer and transformation in complex processes.

P4.2B – Name devices that transform specific types of energy into other types.

P4.2C – Explain how energy is conserved in common systems.

<u>Building a Stirling Engine (Extra Credit)</u>

P1.1f – Predict what would happen if the variables, methods or timing of an investigation were changed.

P1.2f – Critique solutions to problems, given criteria and scientific constraints.

P1.2j – Apply science principles or scientific data to anticipate effects of technological design decisions.

P3.1A – Identify the forces acting between objects in direct contact or at a distance.

P3.2B – Compare work done in different situations.

P3.4A – Predict the change in motion of an object acted on by several forces.

P4.1B – Explain instances of energy transfer by waves and objects in everyday activities.

P4.2A – Account for and represent energy transfer and transformation in complex processes.

P4.2B – Name devices that transform specific types of energy into other types.

P4.2C – Explain how energy is conserved in common systems.

P4.2f – Identify and label the energy inputs, transformations and outputs using qualitative or quantitative representations in simple technological systems.

APPENDIX I B
ELECTRICITY UNIT
MICHIGAN BENCHMARKS COVERED

The benchmarks referred to are found in the Michigan High School Science Content Expectations for Physics published by the Michigan Department of Education in October of 2006.

Study Guide

P4.10B – Identify common household devices that transform electrical energy to other forms of energy, and describe the type of energy transformation.

P4.10C – Given diagrams of many different possible connections of electric circuit elements, identify complete circuits, open circuits and short circuits and explain the reasons for the classification.

P4.10D – Discriminate between voltage, resistance and current as they apply to an circuit.

P4.10e – Explain energy transfer in a circuit, using an electrical charge model.

P4.10f – Calculate the amount of work done when a charge moves through a potential difference, v.

P4.10g - Compare the currents, voltages, and power in parallel and series circuits.

P3.7A - Predict how the electric force between charged objects varies when the distance between them and/or the magnitude of charges change (Coulomb's Law).

Building Circuits Activity

P4.10g – Compare the currents, voltages and power in parallel and series circuits.

P4.10C – Given diagrams of many different possible connections of electric circuit elements, identify complete circuits, open circuits and short circuits and explain the reasons for the classification. (The students are using the actual elements to build circuits rather than just looking at diagrams in this activity.)

List Ways Electricity Can Be Made

P4.10A – Describe the energy transformations when electrical energy is produced and transferred to homes and businesses.

Electrolysis Lab

P4.10B – Identify common household devices that transfer electrical energy to other forms of energy and describe the type of energy transformation.

P1.1C - Conduct scientific investigations using appropriate tools and techniques.

P1.1f - Predict what would happen if the variables, methods or timing of the investigation were changed.

P4.3A – Identify the form of energy in given situations.

P3.7c - Draw the redistribution of electric charges on a neutral object (solution ion in our case) when a charged object is brought near.

<u>Car Battery Demonstration and Student Question Sheet</u>

P1.2g - Identify scientific trade-offs in design decisions and choose among alternative solutions.

P1.2j - Apply science principles or scientific data to anticipate effects of technological design decisions.

P3.7c - Draw the redistribution of electric charges on a neutral object when a charged object is brought near.

P4.2B – Name devices that transform specific types of energy into other types.

P4.10D – Discriminate between voltage, resistance and current as they apply to an electric circuit.

P4.10c - Explain energy transfer in a circuit using an electric charge model.

<u>Voltaic Pile Lab</u>

P1.1C – Conduct scientific investigations using appropriate tools and techniques.

P1.1D – Identify patterns in data and relate them to theoretical models.

P1.1f - Predict what would happen if the variables, methods or timing of an investigation were changed.

P1.2j - Apply science principles or scientific data to anticipate effects of technological design decisions.

P3.7g - Propose a mechanism based on electric forces to explain current flow in an electric circuit.

P4.10g – Compare the currents, voltages and power in parallel and series circuits.

Extra Credit Project: Building A 3-D Model of a Fuel Cell, Hybrid Car Battery or Electric Plug-in Battery

P1.1i - Distinguish between scientific explanations that are regarded as current scientific consensus and the emerging questions that active researchers investigate.

P1.2f - Critique solutions to problems given criteria and scientific constraints.

P3.7g - Propose a mechanism based on electric forces to explain current flow in an electric circuit.

Building a Photovoltaic Cell Lab

P1.1C – Conduct scientific investigations using appropriate tools and techniques.

P1.1A – Generate new questions that can be investigated in the laboratory or field.

P4.2B – Name devices that transform specific types of energy into other types.

P4.10D – Discriminate between voltage, resistance and current as they apply to an electric current.

P4.10g - Compare the currents, voltages and power in parallel and series circuits.

APPENDIX I C
THERMODYNAMICS AND OPTICS UNIT
LESSON PLAN OUTLINE

Text book used: Merrill Physics Principles and Problems, Glencoe McGraw Hill, 1995.

Last Day of Previous Unit (Wednesday, September 26)
Administer the Prior Knowledge Survey.
Assign homework reading: Solar Hot Water: A Primer and accompanying questions.

Day 1 (Thursday, September 27)
Hand back unit 1 test and go over it.
Explain to students how to help collect engagement data for the thesis.
Hand out the Study Guide for this unit.
Students fill in first four terms under II (vocabulary) on the Study Guide.
Go over the four terms.
Ask if there are questions on the homework reading.
Administer the homework quiz.
Go over the homework quiz.

Day 2 (Friday, September 28)
Fill in the definition for specific heat together on the Study Guide.
Fill in specific heat calculations (IVA) together on the Study Guide.
Hand out the Specific Heat Lab.
Read the purpose together.
Students fill in background questions 1-3.
Discuss background questions 1-3 as a class.
Assign background question 4 as homework.
Students copy drawing off board for question 5 (solar hot water system).
Assign additional homework: p.261 (Reviewing): 1-4, 6-9; p.248 (Problems): 5-7; p.262 (Applying): 3-6; p.262 (Thinking Physically): 1a,b.

Day 3 (Monday, October 1)
Put up an overhead of the homework problems worked out.
Ask which ones students would like to see worked out and explained on the board.
Administer the homework quiz.
Students perform the Specific Heat Lab
Homework assignment: Finish lab calculations and write the conclusion.

Day 4 (Tuesday, October 2)
Students turn the Specific Heat Lab in.
Students skim four articles on absorbance and solar heating using highlighters on phrases they deem important.
Class discusses the highlighted parts.
Hand out the Absorbance/Emission Lab.

Read the purpose and background together.
Students do question 1.
Go over question 1.

Day 5 (Wednesday, October 3)

Give a lecture on absorbance and emission.
Fill in 2-4 on Absorbance/Emission Lab together.
Fill in drawing E (transmission, reflection, and absorbance) together on the study guide.
Homework assignment: Research properties of the materials under consideration for use in the Absorbance/Emission Lab.

Day 6 (Thursday, October 4)

Students fill in answers to materials questions on Absorbance/Emission Lab.
Go over materials questions.
Find out which materials each group has decided to use.
Fill in vocabulary terms on the Study Guide together: Control, opaque, transparent, and natural frequency.
Read through procedure aloud and model the steps for the students.
Ask for volunteers to take temperature readings throughout the day tomorrow.
Fill in drawing A (thermometer) on the Study Guide together.
Give a lecture on temperature changes due to heat transfer.
Homework assignment: Bring materials you need for the lab tomorrow.
Also p.252: 9-12 and 1.1-1.4; p.247: 1-3.

Day 7 (Friday, October 5)

Hand out solutions sheet to yesterday's homework.
Ask if there are any questions on the homework.
Absorbance/Emission Lab:
Students gather materials and assemble collectors.
Students set collectors up outside and take readings.
Volunteers take readings throughout the remainder of the day.
Volunteer brings equipment inside at the end of the day.

Day 8 (Monday, October 8)

Disassemble solar collectors, put equipment away and clean up.
Students post data they collected on board for others to transcribe.
Hand back Specific Heat Labs and go over.
Detail what is expected for the analysis section of the Absorbance/Emission Lab.
Homework: Analysis and conclusion sections of Absorbance/Emission Lab.

Day 9 (Tuesday, October 9)

Collect Absorbance Labs
Reteach the material on temperature changes due to heat transfer.
Work out all of the homework problems from day 6 on the board.

Day 10 (Wednesday, October 10)

Students fill in heat of vaporization and heat of fusion under vocabulary on the Study Guide.

Go over the two vocabulary terms.

Students perform the Boiling Water Lab.

Class discussion of the meaning of the shape of the graph from the lab.

Lecture on phase change diagrams and heat transfer in change of state.

Work out sample problems on board: p.255: 13-16.

Homework: p.255: 14, 15, 16a.

Day 11 (Thursday, October 11)

Answers to homework problems are displayed on the overhead.

Work out and explain problems 14 and 16a on the board.

Administer the homework quiz.

Students read aloud p.256-257.

Fill in together on the Study Guide: first law of thermodynamics in the vocabulary section, heat engines and refrigerators in the drawings section.

Homework: Practice drawing the heat engine and refrigerator.

Day 12 (Friday, October 12)

Ask if there are any questions on heat engines or refrigerators.

Administer the homework quiz.

Together, fill in the drawing on the Study Guide for geothermal heat pump.

Students read <u>Suncatchers Tuned to Crank Out the Juice</u> and answer questions.

Fill in Stirling engines together under section V on the Study Guide.

Show the rubric for the extra credit project Building a Stirling Engine.

Homework: Research the payoff time for solar hot water and geothermal heat pump systems in Michigan.

Day 13 (Monday, October 15)

Students read p.258-259 (entropy) aloud.

Fill in under vocabulary on the Study Guide: second law of thermodynamics, energy transfer, and energy transformation.

Read aloud the first two paragraphs of a packet on thermodynamics.

Students build tiny heat engines (rockets).

Hold rocket contest outside to see whose goes the farthest.

Homework: <u>How Does It Work?</u> (questions on heat engines)

Day 14 (Tuesday, October 16)

Students turn in Payoff homework.

Go over "How Does It Work?" question sheet.

Read aloud 1-1/2 paragraphs form p. 7 of Chapter 5 Thermodynamics packet.

Design Your Own Solar Collector Lab:

Read the purpose together.

Draw the two background drawings.

Students fill in #1 (things that can be tested and varied).
Discussion of all the things that could be varied and tested.
In groups of two, students choose the component they would like to vary.
Fill in vocabulary on the study guide: empirical, wave particle duality of light.

Day 15 (Wednesday, October 15)
Design Your Own Solar Collector Experiment
In groups of 2 students brainstorm methods, identify obstacles, refine the plan.
Students each fill out a research proposal.

Day 16 (Thursday, October 18)
Fill in IIIB, IIIC, IIID on study guide.
Finish filling in research proposal.
Students meet with instructor to go over the proposal.
Students work on review problems for the test while waiting for turn with instructor:
p.262/263 (Problems): 1,2,4,6,16,17,19; p.697: 9.

Day 17 (Friday, October 19)
Fill in IIIF, IIIG, IVB, IVC, VA, VB, and VD on the Study Guide.
Students fill in textbook's vocabulary review sheet.
Go over vocabulary review.
Class fills in textbook's study guide together.

Day 18 (Monday, October 22)
Watch video on Tesla.

Day 19 (Tuesday, October 23)
Display solutions to homework problems on overhead.
Ask if there are any questions on the homework.
Display a list of what should be in their notebooks.

Day 20 (Wednesday, October 24)
Unit 2 Test (Thermodynamics and Optics)
Put up chart of specific heats for students' reference during the test.

Day 21 (Thursday, October 25)
Design Your Own Solar Collector Experiment:
Students construct their collectors.
Students perform experiments and record data and observations.

Day 22 (Friday, October 26)
Hand Unit 2 Test back and go over it.
Design Your Own Solar Collector Experiment:
Students get their data from volunteers who collected it.
Students disassemble collectors, put equipment away and clean up.
Students begin lab write-up.

Day 23 (Monday, October 29)

Design Your Own Solar Collector Lab:

Each group presents their findings to the class.

Class discussion of each group's conclusion.

Assignment: Each group post their lab write-ups on our web page.

Turn in notebook of daily work.

Administer Unit 2 Post-Survey.

Administer Prior Knowledge Survey for Unit 3 (Electricity).

Homework: Read p.407, 408, 410, and 411.

Do p.421 (Reviewing): 1-4, 7,8; (Applying): 5.

APPENDIX I D
THERMODYNAMICS AND OPTICS UNIT
COMMENTARY ON LESSON PLAN SCHEDULE

The lesson plan outline written in this thesis is the schedule as it actually occurred. The original lesson plan predicted the completion of the unit in 17 days. It actually took 23 days. Part of the miscalculation was simply due to having a substitute teacher for two days. A second factor was an unusually large number of interruptions and shortened periods due to events such as fire drills, assemblies and school-wide character lessons. A third factor was class demographics. A large percentage of students in this class were weak in mathematics and analytical thinking. They also lacked strong study skills and had lower motivation than my previous physics classes. Plans were adjusted to allow for more explanation during lectures and more guided practice. Also, this was the first year for these activities. The more years I have taught an activity, the more efficient I become at delivery.

Following is a day-to-day commentary on the flow of the lessons.

Last Day of Unit 1 (Wednesday, September 26): This was actually a combination of the last day of unit one and the first day of unit 2. By the time the students finished the Unit 1Test, scored their notebooks of daily work and turned them in, they had only 10 minutes to complete the Prior Knowledge Survey. I had originally told the students that it was worth 10 points if they completed it before the end of the hour. Four students who took longer than the rest on the Unit 1 Test absolutely did not have time to complete the survey so I let them take it home to finish.

Day 1 (Thursday, September 27): The administration shortened our hour today which is why we only got as far as the homework quiz.

Day 2 (Friday, September 28): We ran short on time at the end of the hour for the students to be able to complete all of #4 on the specific heat lab which was looking up the characteristics of the liquids they planned to test. With 5 minutes left in the hour when the students started #4, there was time to look up characteristics for at least one liquid.

Day 3 (Monday, October 1): Students had time to test only 2 of the 3 substances and some had to get passes to the next class because it took longer than our 55 minute class period.

Day 4 (Tuesday, October 2): The labs were due today. None of the students had looked up the accepted specific heats. I wrote the values on the board and gave them a couple of minutes to do the percent error calculation. Most students struggled with that and I had to give them more time. A fire drill interrupted the class part way through. The result was that we only completed tasks up through the background question #1in the Absorbance and Emission Lab. I decided that day, that due to the level of skills and motivation in this particular class, I needed to plan on going much slower than I had originally planned. Otherwise concepts would go right over their heads and the time would be wasted.

Day 5 (Wednesday, October 3): It took 35 minutes to explain, give notes and draw the concepts of absorbance, emission, and transmittance.

Day 6 (Thursday, October 4): The students were so absorbed in discussing the different aspects of the lab that the notes on calculating final temperature got rushed. We had to cram them into the last 10 minutes of the period. But the quality of thought that they verbalized during discussion was rewarding. One topic they thoroughly hashed over was how one could keep surface area constant while varying mass. They decided it was definitely easier to keep mass constant and vary surface area. The mass could simply be broken up into smaller pieces. But since it was important to figure out how to keep surface area constant, there was quite a discussion about whether the surface facing the sun was the only surface area that mattered. One student pointed out that after the sun's rays are absorbed they are later emitted as infrared from ALL of the object's surfaces, not just those facing the sun.

Day 7 (Friday, October 5): Preparing the collectors took most of the period so the bulk of the temperature readings were taken by a few volunteer students who were able to get out of class for a few moments later in the day.

Day 8 (Monday, October 8): The specific heat labs I graded were very poorly done so I spent a lot of time this day talking about what I expected in the analysis and conclusion section of the next lab (Absorbance and Emission).

Day 9 (Tuesday, October 9): I spent the whole hour re-explaining, redoing the lecture notes, this time in more detail, and doing example math problems on the board.

Day 10 (Wednesday, October 10): The schedule went smoothly. Their misconceptions about the boiling water transitioned nicely into the explanation of heat of vaporization and heat of fusion.

Day 11 (Thursday, October 11): The schedule went as planned. The students seemed to understand the math problems (which are review from the chemistry they had last year) so no extra time was needed.

Day 12 (Friday, October 12): I had originally planned to also begin building the rockets on this day, but there was not time to even start them. It was probably for the best to wait and do it all the same day anyway. The partly done rockets would have to have been labeled with the students' names and stored somewhere so that they wouldn't get damaged.

Day 13 (Monday, October 15): I had hoped to be able to go over the follow-up questions on rockets "How Does It Work?". But it took the students longer to complete the questions than I had anticipated, so we had to go over them the next day.

Day 14 (Tuesday, October 16): Going over the questions that I had hoped to go over yesterday cut into some of the time we could have used to fill in more parts on the study guide. Stopping at #2 (deciding which parameter to vary) worked out really well for the "Design Your Own Solar Collector Lab". It gave the students overnight to do a little thinking about it.

Day 15 (Wednesday, October 17): Today was the day to brainstorm, design the experiment and begin filling out the research proposal. Four students were absent.

Day 16 (Thursday, October 18): It took substantially longer than expected to meet with each group to discuss their research proposal. I spent a lot of time with individual groups explaining why their design really had more than one variable and trying to guide them to think on their own about how they could design their protocol so there was only one variable. I also had to point out for most that their design was not really going to test the stated hypothesis. Some groups hadn't included a method for data collection, so that had to be addressed. The was not enough time to move the groups through all of these challenges in this class period.

Day 17 (Friday, October 19): The substitute teacher helped the students fill in the study guide and handed out the two review items for them to work on.

Day 18 (Monday, October 22): I asked the substitute teacher to show a video as I wanted to teach as much of the thesis units myself as possible.

Day 19 (Tuesday, October 23): Last week I assigned math problems to review for the unit test. Lots of students asked questions about these today. So, more time was needed to explain the problems than had been anticipated. I met with groups again about their research proposals and some had not put any additional thought into the problems we had discussed at our last meeting. Much of the hour had to be spent walking them through problem solving.

Day 20 (Wednesday, October 24): Three students came in before school to spray paint their absorbers. This saved time. Next year I will push for all of the students to do this. The students were able to finish the test in the time allotted.

Day 21 (Thursday, October 25): We had a shortened hour today for "Character Counts" lessons. The students really had to hustle to get their collectors put together and taken outside. They were very efficient and focused. It went very smoothly. To be able to gather data over a long enough period for the collector to heat up and cool back down, students had to get creative about taking data. (Physics class meets second hour.) Different members of each group utilized part of their lunch hours. Students whose route between classes took them near their collector dashed outside enroute to take data. One boy also has a class with me 6^{th} hour, so took some reading then. And one member of each group stayed after school to take final readings and bring equipment back into the classroom. This went very smoothly and the students seemed to rise to meet this extra responsibility.

Day 22 (Friday, October 26): One group did not get their equipment outside yesterday. The members of this group are meticulous, careful and insightful, so I prefer not to rush them. It was cloudy on this day and this group had not collected any data yet. Their solution was to put their collectors under a heat lamp in the classroom. They stopped in throughout the day to collect data, turning the lamp off part way through so they could collect cooling data also. There was plenty of time during the hour for the other students to disassemble their collectors, put equipment away, clean up, get data from the other group members and go over the Unit 2 Test. Most also began working on the lab write-up.

Day 23 (Monday, October 29): There was little discussion from the class in response to group presentations of their lab results. So there was plenty of time for them to complete the Post Survey for this unit and the Prior Knowledge Test for the Electricity Unit.

APPENDIX I E
ELECTRICITY UNIT
LESSON PLAN OUTLINE

Page numbers refer to the text "Merrill Physics Principles and Problems" by Zitzewitz, Davids, Neff and Wedding, published by Glencoe McGraw-Hill. Copyright 1995.

Last Day of Previous Unit – Monday, October 29

Prior Knowledge Survey
Homework: Read p. 407, 408, 410 and 411.
Do p. 421 (Reviewing): 1-4, 7,8; (Applying): 5.

Day 1 – Tuesday, October 30

Questions on homework?
Homework Quiz
Fill in definitions for insulator, conductor, charging by a conductor and charging by an inductor on the Study Guide.
Fill in Coulomb's Law on the Study Guide in both the vocabulary section and in the math equation section.
Do together: p. 422 (Applying); 12,13; (Problems): 1

Day 2 – Wednesday, October 31

"What is Electric Current?" handout together
Fill in the definitions for electric current and ampere on the Study Guide
Go over the definitions
"What is a Series Circuit?" handout together
"What is a Parallel Circuit?" handout together

Day 3 – Thursday, November 1

Building Circuits Activity

Day 4 – Monday, November 5

Read p. 431 to the top of p. 433.
Notes on Electric Potential
Define electric potential and give its units.
Video: Principles of Technology #1, first and third segments Force is Pressure
Play with the Vandergraff generator.

Day 5 – Wednesday, November 7

List different ways electricity can be made (energy transformations).

Discussion of devices that accomplish energy transformations
Notes on electrolytic cells
Electrolysis Lab
Go over the lab

Day 6 – Thursday, November 8

Read p. 447 – 451.
Fill in the definitions and math equations for electric power and coulomb on the Study Guide.
Do p. 451: 1-4.
Go over p. 451: 1-4.
Make a labeled drawing of a closed circuit on the Study Guide.
Chirping chickie demonstration.
Notes on resistance and Ohm's Law
Ohm's Torture (silly drawings to remember the ohm symbol)
Homework p. 454: 5-10

Day - Friday, November 9

Answers to homework problems on the overhead
Questions on homework?
"What is Electrical Resistance?" handout together
Notes on resistors and controlling current
"What are Amperes, Volts and Ohms?" handout together
Notes on series and parallel circuits with meters

Day 8 – Monday, November 12

On the Study Guide fill in the definition for resistance, ways current can be controlled and fill in Ohm's Law in the math equations section.
Notes and demonstration on how to use the multi meter
Pocket Lab p. 455. Students get my signature next to each drawn circuit when they have successfully built it and measured V, I and R.

Day 9 – Tuesday, November 13

Answers to homework questions on the overhead
Questions on homework?
Quiz over basic electricity
List of what should be in the daily work notebook so far (on the overhead)

Day 10 – Wednesday, November 14

Catch up day:
Finish Building Circuits Activity

Finish p. 455 Pocket Lab

Day 11 – Thursday, November 15

Video on Nickoli Tesla

Day 12 – Friday, November 16

Labeled drawing and notes on the car battery
Car Battery Demo
Student Question Sheet for accompany Car Battery Demo
Discuss students' answers
Notes on examples of half-cell reactions in hybrid car batteries
Slide show of hybrid cars

Day 13 – Monday, November 19

Fill in first 9 vocabulary terms on the Study Guide together.
Voltaic Pile Lab
Finish the hybrid car slide show.

Day 14 – Tuesday, November 20

Discuss the Voltaic Pile Lab.
Notes on reduction potentials
Labeled drawings of a fuel cell (staple to the Study Guide)
Highlights of how a fuel cell works
Extra credit option: Building a 3-D Model of a Fuel Cell, Hybrid Car Battery or an Electric Plug-in Battery
Homework: Read "Photovoltaics" article from the National Renewable Energy Laboratory

Day 15 – Tuesday, November 27

Questions on the homework reading?
Homework quiz
Notes on comparing and contrasting PV cells with galvanic cells
Building a PV Cell Lab (Day 1)

Day 16 – Wednesday, November 28

Building A PV Cell Lab (Day 2)
Test the photovoltaic cell.
Homework: Read "Discussion" photocopy and make a labeled drawing of the PV cell and answer the post lab questions

Day 17 – Thursday, November 29

p. 459: 14, 15, 16, 17 ($E = Pt$ and $P = VI$)
Go over the math problems.
Read p. 460 – 462 aloud.
Fill in definitions for high voltage lines on the Study Guide and fill in the math equations for kilowatt hour and transmitting power
Principles of Technology Video #3 (electric rate section)
p. 464: 1-11 and also draw #8.

Day 18 – Friday, November 30

Go over p. 464: 1-11 and drawing of #8.
Sample cost problem
Read examples of operating costs of various appliances from a Consumer's Energy brochure.
p. 465 (Problems): 2, 5, 6, 8, 9, 14
Go over p.465 problems.
List of what should be in the daily work notebook so far (on an overhead)

Day 19 – Monday, December 3

Vocabulary Review (textbook company's version)
Fill in remainder of our Study Guide
Study guide (textbook company's version)

Day 20 – Tuesday, December 4

Unit Test
Score notebook of daily work and turn in.

First Day of Next Unit – Wednesday, December 5

Post Survey
Hand back tests and go over.
Begin next unit.

APPENDIX II UNIT STUDY GUIDES

APPENDIX II A
STUDY GUIDE FOR THERMODYNAMICS AND OPTICS

I. Resources
   Text book p. 242 – 260 (Thermodynamics)
   p. 368 – 403 (Optics)

II. Vocabulary

Thermal Energy

Temperature

Heat

Thermal Equilibrium

Specific Heat

Conservation of Energy

First Law of Thermodynamics

Entropy

2^{nd} Law of Thermodynamics

Control

Opaque

Transparent

Natural Frequency

Empirical

Energy Transfer

Energy Transformation

Wave/Particle Duality

Heat of Fusion

Heat of Vaporization

III. Labeled Drawings

A. Fahrenheit, Celsius and Kelvin Thermometers

B. Solar hot water heating system for cold climates

C. Two objects of different temperatures

D. Two objects with different thermal energies, but the same temperatures

E. Transmission, Reflection and Absorption (include angle of incidence/reflection)

F. Solar Collector with glazing that has a coating to block IR

G. Electromagnetic spectrum. Label ends as high/low energy, high/low frequency, short/long wavelength

H. Heat Engine (and refrigerator and 1st Law of Thermodynamics)

I. Geothermal Heat Pump (in winter and in summer)

IV. Calculations

A. Specific Heat

B. Temperature Changes Due to Heat Transfer

C. Heat Transfers Needed to Affect Changes of State

V. Research

A. Specific Heat Lab for Solar Collectors

B. Absorbance/Radiation Lab

C. Stirling Engine (Building one is optional and extra credit. Knowing this material is not optional.)

D. Design Your Own Solar Collector Experiment

APPENDIX II B
TEACHER'S KEY
STUDY GUIDE FOR THERMODYNAMICS AND OPTICS

I. Resources

Text book p.242 – 260 (Thermodynamics); p.368 – 403 (Optics)

II. Vocabulary

Thermal Energy: **Sum of KE + PE of the particles in an object. Size (number of particles) does affect sum of KE and PE.**

Temperature: **Average KE of the particles in an object. Size of object does not affect temperature as we divide by number of particles to get average.**

Heat: **Energy that flows due to a difference in temperature.**

Thermal Equilibrium: **When there is an equal amount of heat flowing from A to B as from B to A. Their temperatures will be equal, but their thermal energies may be different.**

Specific Heat: **Amount of heat that must be added to raise the temperature of 1 kg of a substance 1 degree Kelvin. Water has a high specific heat.**

Conservation of Energy: **Energy can neither leave nor enter a closed isolated system. If energy increases in one part of the system, it must decrease in another part of the system.**

First Law of Thermodynamics: **The total increase in the thermal energy of a system =(work done on it) + (heat added to it).**

Entropy: **Common usage: disorder. If considering gravity: the outcome or sequence of events that is most likely to happen.**

2^{nd} Law of Thermodynamics: **Things spontaneously go in the direction which results in the greatest entropy.**

Control: **A means of measuring the variation inherent in the system.**

Opaque: **Will not transmit electromagnetic waves of the frequency of interest.**

Transparent: **Will transmit electromagnetic waves of the frequency of interest.**

Natural Frequency: **Wave frequency that corresponds to the difference in the electrons' energy levels within the atom.**

Empirical: **Objective measurement that can be agreed upon by two independent researchers, usually quantitative.**

Energy Transfer: **Moving energy from one location to another, like moving sun's energy from the absorber in a solar collector to water in the pipes.**

Energy Transformation: **Changing energy from one form to another, like changing light energy to electrical energy in a photovoltaic cell.**

Wave/Particle Duality: **All electromagnetic forms of energy can be observed to behave as waves or particles, but never both simultaneously. It acts like a wave when there is constructive or destructive interference, and like a particle when it physically hits an electron increasing its**

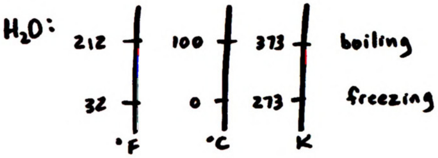
energy.

Heat of Fusion: **Amount of heat required to melt 1 kg of a solid.**

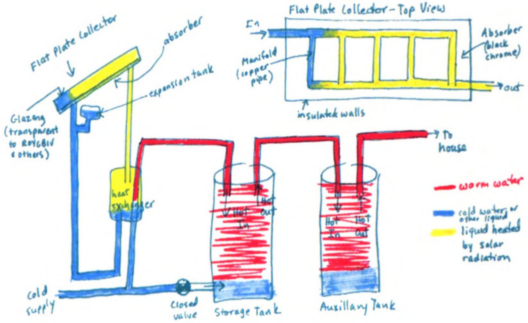
Heat of Vaporization: **Heat needed to change 1 kg of liquid to gas.**

III. Labeled Drawings (teacher answer key)

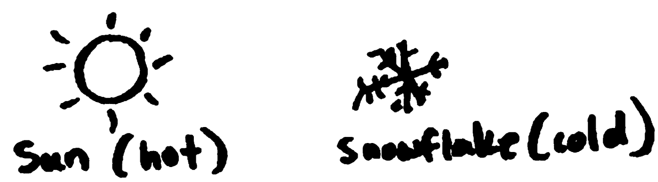
A Fahrenheit, Celsius and Kelvin Thermometers



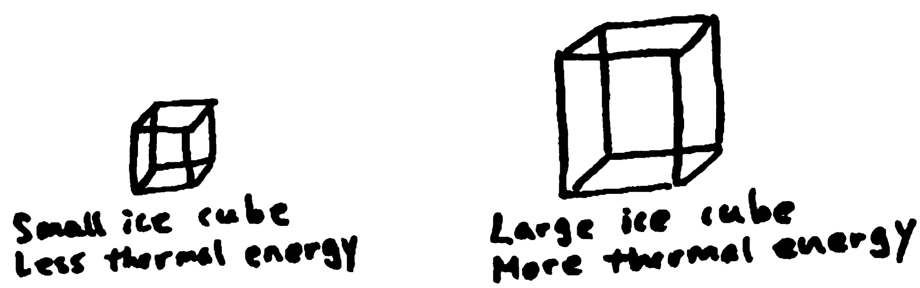
B Solar hot water heating system for cold climates



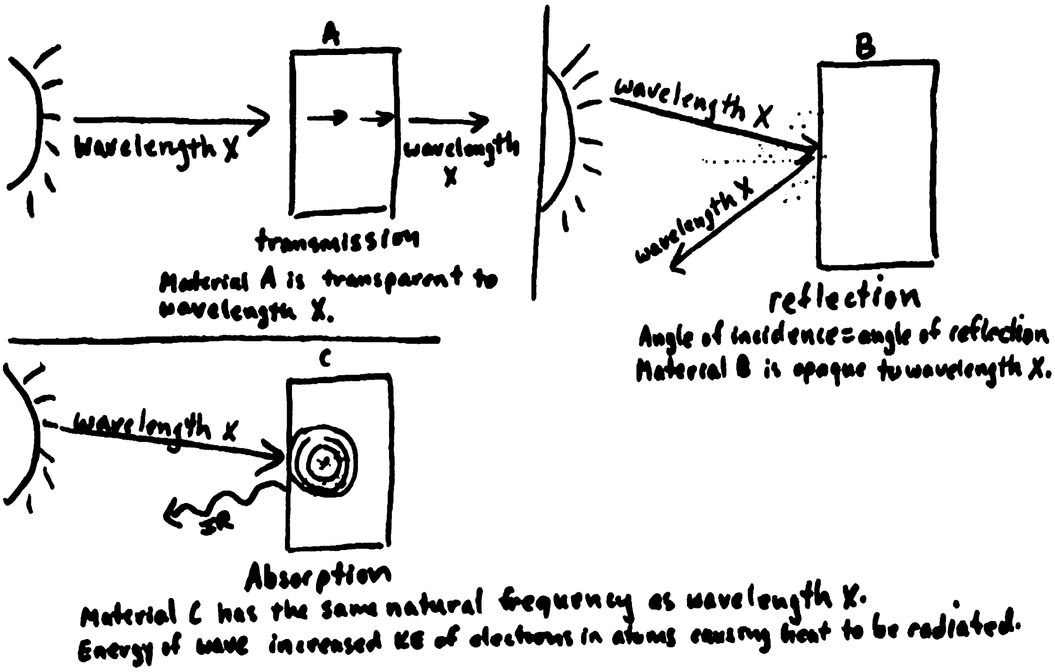
C. Two objects of different temperatures



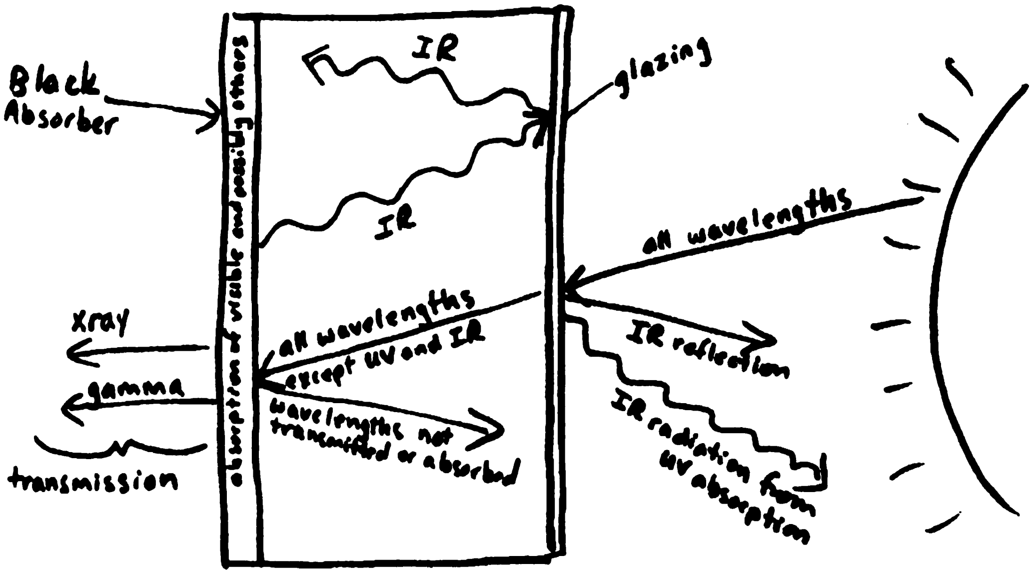
D. Two objects with different thermal energies, but the same temperatures



E. Transmission, Reflection and Absorption (include angle of incidence/reflection)

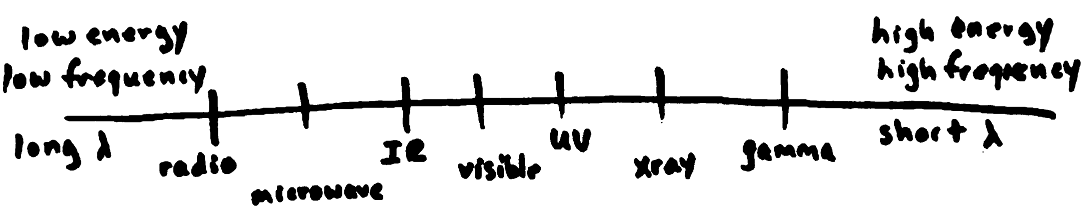


F. Solar Collector with glazing that has a coating to block IR



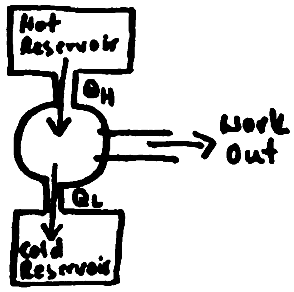
The broader the range of frequencies absorbed by the absorber, the more IR radiated by the absorber. Glazing that is not transparent to IR traps heat inside (greenhouse effect).

G. Electromagnetic spectrum. Label ends as high/low energy, high/low frequency, short/long wavelength.

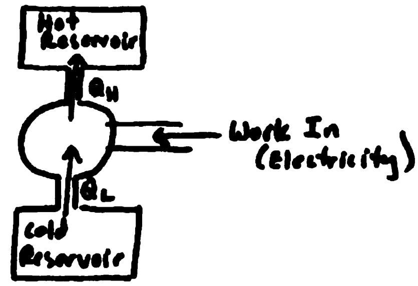


H. Heat Engine (and refrigerator and 1st Law of Thermodynamics)

Purpose: To convert thermal energy to mechanical energy.



Heat Engine

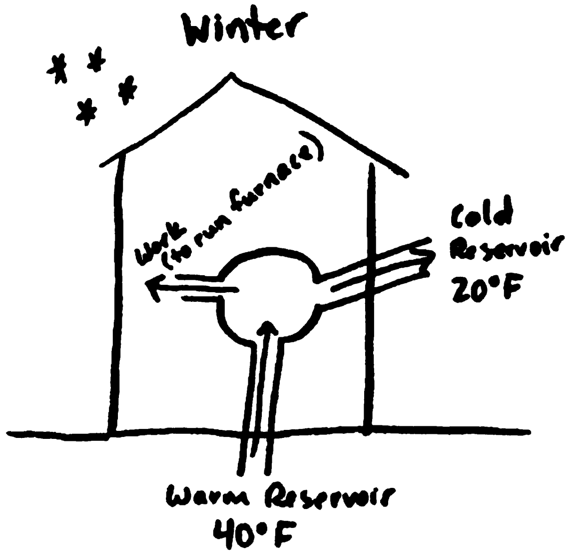


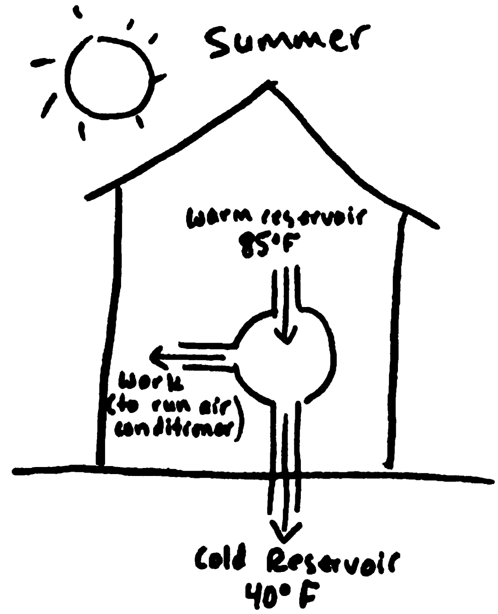
Refrigerator - You can get a heat engine to run backwards by adding energy. It takes thermal energy out of the food in refrigerator and dumps it into the warm kitchen.

1st Law: $Q_H = Q_L + Work$

$Q_H - Q_L = Work$ So the larger the difference in temperature, the more work.

I. Geothermal Heat Pump (in winter and in summer)





Works well in Michigan because there is a big temperature difference between the hot and cold reservoirs in summer and in winter.

IV. Calculations

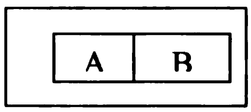
A. Specific Heat

$Q = m\,C\,\Delta T$

Q = heat in calories or joules
m = mass in kilograms or grams
C = specific heat in J/kgK or cal/g°C
$\Delta T = T_f - T_i$ in Kelvin or °C

In a closed, isolated system the total amount of energy remains constant. The heat energy, Q, lost by one part of the system equals the Q gained by another part of the system. Example: All of the heat lost by the metal is gained by the liquid in the calorimeter.

B. Temperature Changes Due to Heat Transfer



$$Q_A = -Q_B$$
$$m_A C_A \Delta T_A = m_A C_A \Delta T_A$$

C. Heat Transfers Needed to Affect Changes of State

melting: $Q = mH_f$
freezing: $Q = -mH_f$
vaporizing: $Q = mH_v$
condensing: $Q = -mH_v$

H_f = heat of fusion (look up on a chart)

H_v = heat of vaporization (look up on a chart)

V. Research

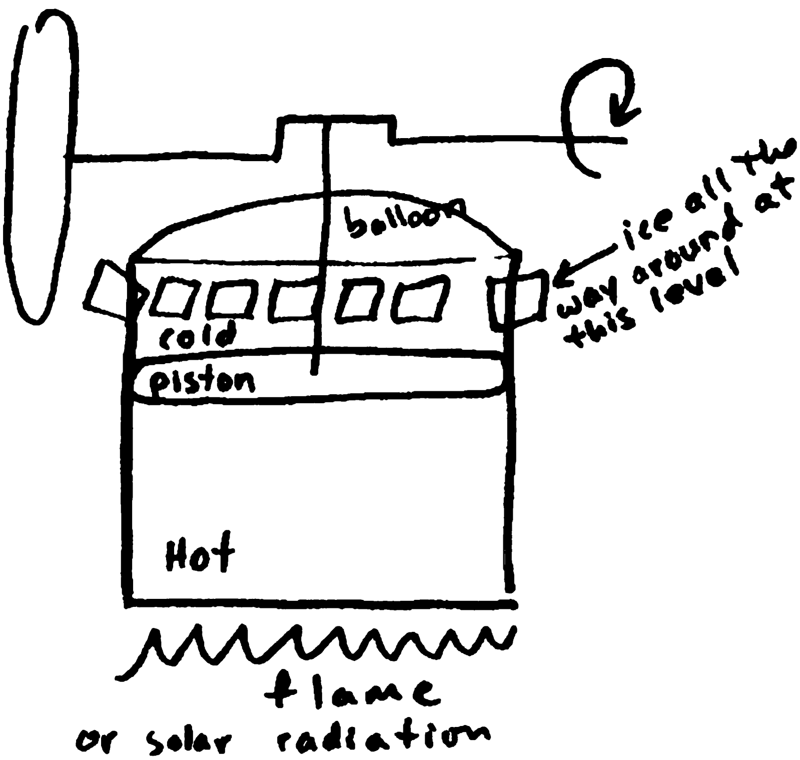
A. Specific Heat Lab for Solar Collectors

1. **Tell which of the 3 liquids would be best suited for use in the manifold of a closed-loop hot water heater system. Use empirical evidence from your lab to support your claim.**
2. **List some possible sources of error.**
3. **Explain your choice of follow-up studies.**

B. Absorbance/Radiation Lab

1. **Suggest specific improvements that could be made in the procedure.**
2. **Predict the outcome if the procedure is changed or different variables are tested.**

C. Sterling Engine (Building one is optional and extra credit. Knowing this material is not optional.)



(teacher answer key)

To start the engine, heat is applied to the bottom and cold to the top. The crank is slowly turned until the engine starts. Hot air expands, pushes the piston up. The balloon poofs up, turning the crank. Hot air is now partially in the cold end so it cools and condenses. The balloon collapses down, turning the crank. There is no combustion so it's quiet, also no exhaust. Solar radiation can be the heat source for the hot reservoir.

D. Design Your Own Solar Collector Experiment

1. **State three new questions you have in regards to solar heating systems that could be investigated in an empirical manner.**
2. **Pick one of the questions and describe how you would test it. Be sure to identify the variable and describe your control.**

APPENDIX II C
STUDY GUIDE FOR THERMODYNAMICS AND OPTICS UNIT
ANECDOTAL COMMENTARY

The study guide was filled in gradually over the course of the unit as the various concepts were encountered. On the vocabulary terms, I sometimes told students what to write in for the definitions. Other times I would have the students fill them in and then we would go over them as a class to be sure they hadn't omitted a key aspect or important distinction.

I drew the labeled diagrams on the board as I gave background and/or explained the function of the parts and the whole. The space I allotted on the study guide for IIIB, Solar Hot Water Heating System, was inadequate. Students drew it on a separate sheet of paper and stapled that page to their study guide. Also, for that particular drawing I used different colored markers on the board and students used colored pencils. Liquid heated by solar radiation (propylene glycol) was yellow. Cold propylene glycol, as well as cold water, was blue. Water heated by the heat exchanger was red. I did not end up having them fill in anything under V Research A, B and D as there was not room nor time for extensive questions about those on the unit test.

The students thought the drawing of the hot water system was getting pretty complex before we finished it. But adding the colors seemed to help. I walked over to one student who looked very confused and showed her exactly where to put the blue versus the yellow on the heat exchanger portion of the drawing. She said, "Oh, now that makes sense."

For some of the topics that I gave lecture notes on, we waited until later to fill that information in on the study guide. That way it could be revisited again for review during the couple of days before the unit test. Some sections were filled in directly on the study guide in place of taking separate lecture notes. This strategy was employed most often with the vocabulary terms.

The electromagnetic spectrum was included under labeled drawings even though it should have been review for the students. Accurate knowledge of the relative frequencies and energies leads to a better understanding of a material's transmission, absorption and reflection properties. And this year, as usual, I found that many students had either forgotten or never learned the basics of the electromagnetic spectrum.

The students appreciated having a separate section of the study guide for math equations. In the past, the topics on my study guides were arranged chronologically as far as when we encountered each in the unit. As a result, the math equations were sprinkled throughout. There was not a good way for students to be sure they hadn't omitted one if they had been absent. So, students were always asking me to list all of the formulas when we did our review. This year they were already together in one spot.

When filling in the math sections of the study guide, we only included the formula, what each variable stands for, values of any constants, and one or two tips to remember when doing this type of problem (if applicable). Students who get overwhelmed with derivations of formulas were relieved when we filled in the math section on the study guide. "Oh, is this all we have to know?" I did remind them that they also needed to practice doing math problems with the formulas.

APPENDIX II D
ELECTRICITY STUDY GUIDE

I. Vocabulary

Electrochemical reaction

Physics current

Conventional current

Electrolytic cell

Battery

Anode

Cathode

Discharge

Charge

Fuel cell

Direct current

Alternating current

Heaters, ovens, toasters

Photovoltaic cell

Doping

High Voltage lines

Voltage

Coulombs Law

Insulator

Conductors

Charging by conduction

Charging by induction

Coulomb

Ampere

Electric Power

Resistance

Electric Potential

Electric current

Controlling current

II. Labeled Drawings

A. Schematic Symbols

B. Closed Circuit

C. Parallel and Series Circuit

D. Current Flow

E. Electrolytic Cell

F. Ammeters and Voltmeters

G. Car Battery

H. Fuel Cell

I. Photovoltaic Cell

III. Math Equations

A. Coulombs Law

B. Power

C. Ohm's Law

D. Transmitting Power

E. Kilowatt Hour

APPENDIX II E
TEACHER'S KEY FOR ELECTRICITY STUDY GUIDE

I. Vocabulary

Electrochemical reaction: **A reaction that produces electrons.**

Physics current: **is the flow of charged particles, usually electrons.**

Conventional current: **is the flow of positive charge. It is in the opposite direction of the flow of electrons. It was established at the time of Ben Franklin, before it was known that electricity is the flow of electrons.**

Electrolytic cell: **Electricity must be supplied. This cell uses the electricity to power electrochemical reactions. It is a battery that is running backwards.**

Battery: **One or more cells in which chemical potential energy is converted to electrical energy by way of an electrochemical reaction.**

Anode: **The electrode, or terminal, from which electrons leave. In a battery the identity of the anode and cathode swap places depending upon whether the battery is charging or discharging.**

Cathode: **The electrode, or terminal, through which electrons enter.**

Discharge: **The unit is acting as a battery, converting chemical potential energy to electrical energy.**

Charge: **The unit is acting as an electrolytic cell, converting electrical energy to chemical energy. Electricity must be supplied to get non-spontaneous chemical reactions to happen.**

Fuel cell: **converts chemical energy to electrical energy. Similar to a battery except that the reactants continually enter the cell from outside the cell.**

Direct current: **was championed by Thomas Edison. Electrons flow continuously in one direction only.**

Alternating current: **Nikola Tesla argued for this type at the time that Edison was installing power stations at every city block. It can be transported longer distances than direct current. The direction of electron flow changes direction at regular intervals. In the US the direction changes 60 times per second.**

Heaters, ovens, toasters: **convert electrical energy to thermal energy. As electrons fight their way through the resistor (element, coil) the resulting friction causes heat and light to be given off.**

Photovoltaic cell: **Photons from the sun hit the PV cell and create energy by means of the photoelectric effect. The physical structure is similar to a battery. There is an anode, a cathode and an electrolyte.**

Doping: **means adding impurities on purpose. It is done to semiconductors to get more free-flowing electrons and thus a larger current.**

High Voltage lines: **are used to transmit electrical power. Increasing the voltage allows a higher amount of power to be transmitted with current remaining low. (P=VI) Current needs to be kept low to reduce the amount of power lost as thermal energy as there is a lot of resistance and friction in the long wires. Thermal energy loss = $P = I^2R$.**

Voltage: **the units of electric potential.**

Coulombs Law: **The strength of the force between two charged objects is proportional to the magnitudes of the charges and inversely proportional to the square of the distance between them.**

Insulator: **material through which charges have trouble moving. Examples are glass, dry wood, most plastics, dry air.**

Conductors: **materials that allow charges to move freely. Examples are metals and graphite.**

Charging by conduction: **charging a neutral body by touching it with a charged body.**

Charging by induction: **charging without physically touching. Example: a negatively charged rod causes electrons in a nearby object to move away from the rod. The portion of the object with few electrons becomes positive.**

Coulomb: **6.25×10^{18} electrons**

Ampere: **(Amp or A) the unit of current, rate of flow of electrons.
One amp = one Coulomb per second.**

Electric Power: **(P) the rate at which energy is transferred. Units of power is the Watt.**

Resistance: **opposes the flow of electrons. The more friction is generated by the electrons moving through the material, the higher the resistance. Friction can cause heat and or light to be emitted.**

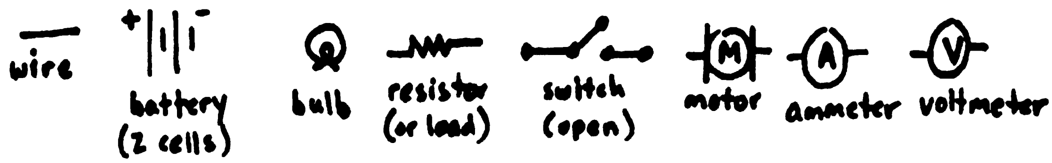
Electric Potential: **(voltage) the difference in potential energy or charge. It is the push behind the electron flow. It is a result of how badly the electrons want to get to the positive charge. The bigger the difference in potential energy, the more they want to get there. Units: Volts.**

Electric current: **(I) the flow of charged particles, positive or negative. It can be controlled by varying the voltage (adding or removing batteries, or turning the dial on the power source), or by varying the resistance (adding or subtracting resistors, changing the identity of the wire, changing the length of the wire, using a potentiometer).**

Controlling current: **It can be controlled by varying the voltage (adding or removing batteries or turning the dial on the power supply) or by varying the resistance (adding or subtracting resistors, changing the length of the wire perhaps by using a potentiometer or by changing the identity of the wire),**

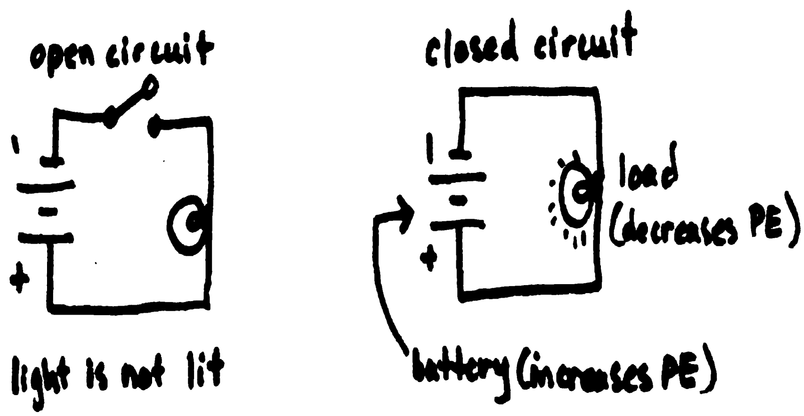
II. Labeled Drawings (teacher answer key)

A. Schematic Symbols

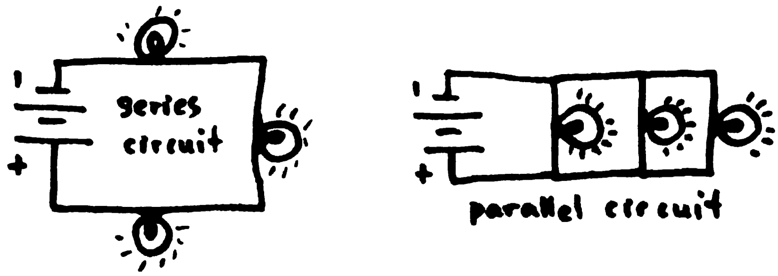


B. Closed Circuit

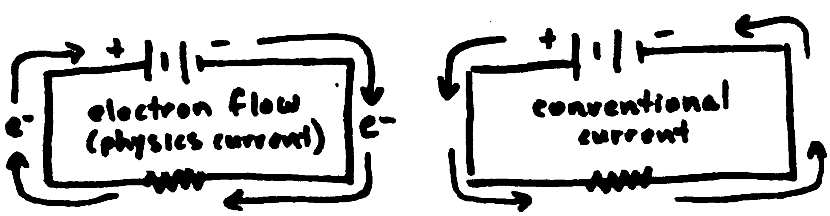
To get current to flow you must have a conductor, a potential difference and a closed loop.



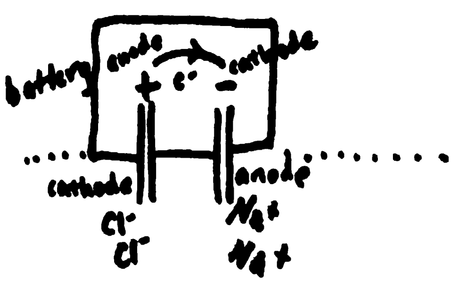
C. Parallel and Series Circuit



D. Current Flow



E. Electrolytic Cell



$NaCl_{(aq)} \rightarrow Na^+_{(aq)} + Cl^-_{(aq)}$

$Na^+ + e^- \rightarrow Na$

$2HOH \rightarrow 2H_{2(g)} + 2OH$

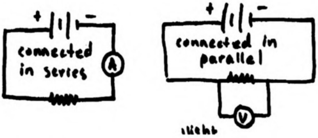
$Na + OH \rightarrow NaOH$

Electrolytic cell

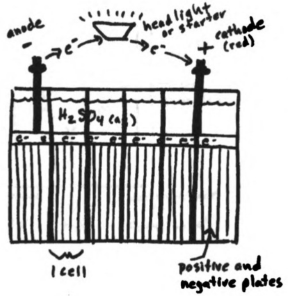
Input of current from battery causes non-spontaneous reaction to happen.

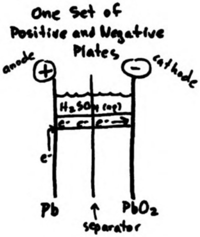
End products here: H_2 gas and $NaOH$, $Cl_{2(g)}$

F. Ammeters and Voltmeters



G. Car Battery





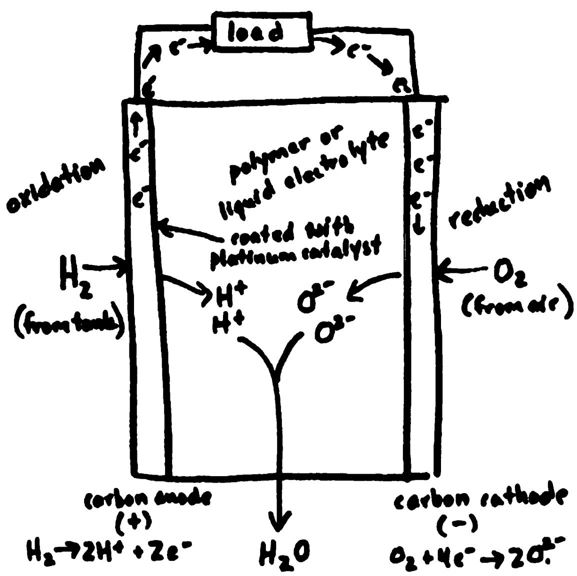
<u>Discharging</u> (Acting like a battery):
electrolyte: $H_2SO_4 \rightarrow 2H^+ + SO_4^{2-}$
at the anode: $Pb + SO_4^{2-} \rightarrow PbSO_4 + 2e^-$
at the cathode: $PbO_2 + 4H^+ + SO_4^{2-} \rightarrow PbSO_4 + 2H_2O$

<u>Charging</u> (Acting like an electrolytic cell):
Electricity is applied and the reactions above run backwards.

H. Fuel Cell

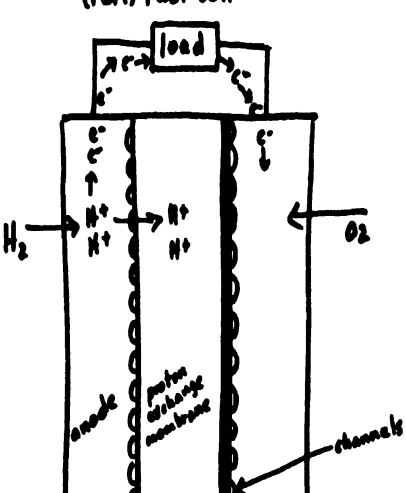
A battery has its chemicals stored inside and eventually they all get converted to product. In a fuel cell, the chemicals (reactants) constantly flow into the cell from outside. So it never goes "dead" like a battery.

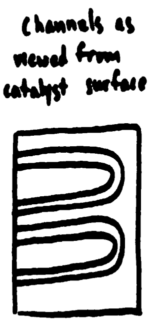
Generic Fuel Cell



Overall reaction: $2H_2 + O_2 \rightarrow 2H_2O$
No pollution!
Uses O_2 from air and H_2 which is plentiful but explosive.

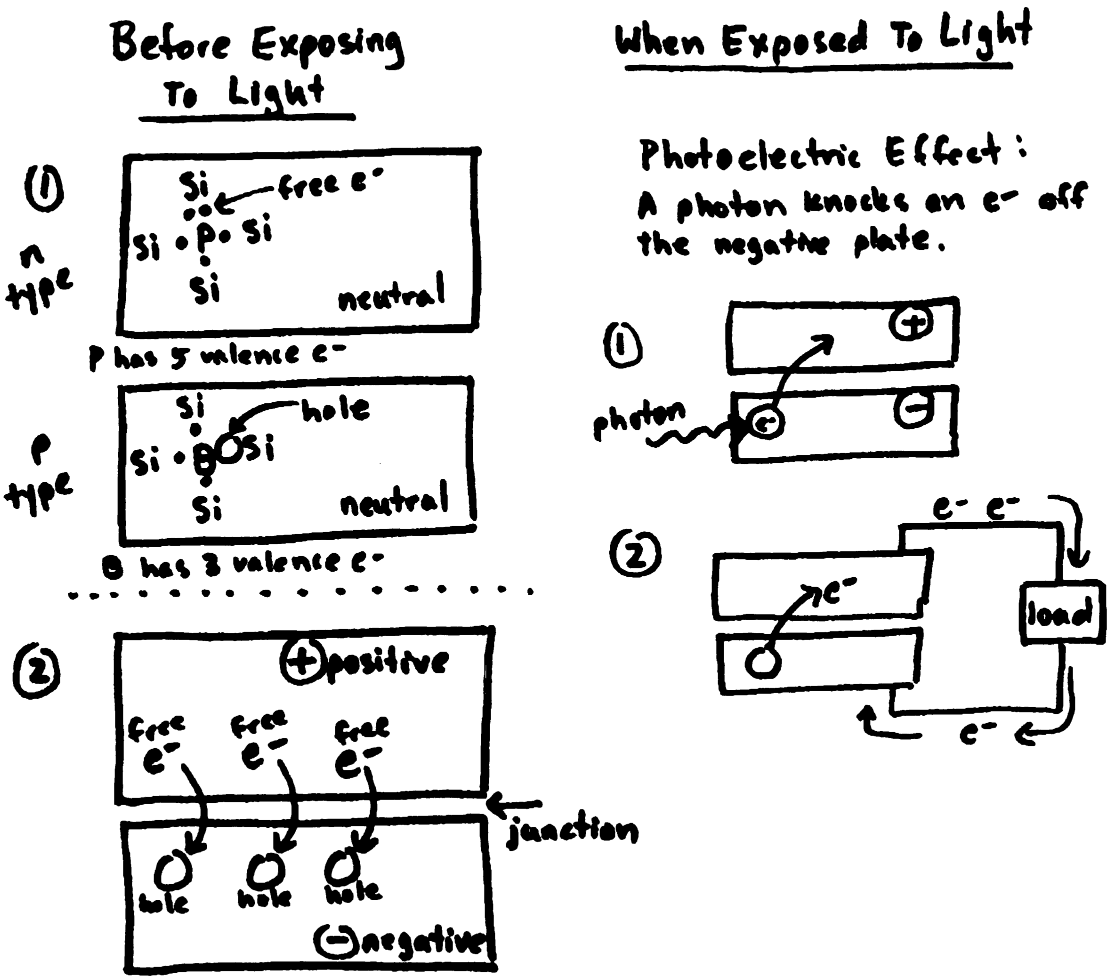
Polymer Exchange Membrane
(PEM) Fuel Cell





<u>Anode</u>: conducts e^- freed from H_2 to the external circuit and has channels to disperse the H_2 gas evenly over the catalyst.
<u>Cathode</u>: has channels to disperse O_2 over the surface of the catalyst and conduct e^- from the external circuit so they can combine with H^+ and O to make water.
<u>Electrolyte</u>: (the membrane) looks like Saran wrap and must be hydrated to work. It blocks e^- so they have to go through the external circuit, and it conducts H^+.
<u>Catalyst</u>: Thin coat of platinum nanoparticles on carbon paper or cloth. It is rough and porous so has lots of surface area for H^+ and O to react on. Speeds up the reaction.

I. Photovoltaic Cell



III. Math Equations

A. Coulombs Law

$F \alpha 1/d^2$ or $F = Kqq'/d^2$

q and q' are charges of the objects
k is a constant
d is the distance between the objects' centers

B. Power

P = VI

P = power in Watts
V = potential difference in volts
I = current in amps

1 Watt = 1 VA

C. Ohm's Law

V = I R

R = resistance in ohms (Ω)

D. Transmitting Power

Substitute V = I R into P = V I:

P = (IR) I
$P = I^2 R$ and since we are referring to thermal energy: $Q = I^2 R$

Energy = E = P t

P = power in Watts
t = time in seconds
E = energy in joules

E. Kilowatt Hour: **1000 Watts delivered continuously for 3600 seconds (one hour)**

1 kWh = (1000W)(3600s)
= (1000J/s)(3600s) = 3.6×10^6 Joules

APPENDIX II F
ELECTRICITY STUDY GUIDE
ANECDOTAL COMMENTARY

Most of the vocabulary terms were filled in together as a class. We just filled in a few at a time on days when those terms related to the day's lesson. Students were quite focused at these times. On the day before the test, as a part of our review, we filled in the parts of the study guide that had not yet been done.

I got totally mixed up when drawing out the electrolysis diagram for them to fill in. It had been two weeks since the electrolysis lessons, and this had been brand new material for me as well as for the students! I was confused about direction of flow of electrons and sign of charge on the terminals when the cell was running backwards and acting as a battery. I have since decided to focus on the fact that electrons leave the anode to avoid confusion in the future.

Students expressed anxiety over the problems on the test related to labeled diagrams. I suggested that they do multiple drawing of all of the labeled diagrams to be sure that they could reproduce them. Most agreed that having all of the drawings on the study guide did help ease the worry of exactly what would be covered on the test and helped focus their study.

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USING ALTERNATIVE ENERGY CONCEPTS AND HANDS-ON ACTIVITIES TO TEACH PHYSICS BENCHMARKS AND INCREASE STUDENT MOTIVATION: THERMODYNAMICS, OPTICS AND ELECTRICITY

VOLUME II

By

Jerri Lynn Amos Osmar

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Interdepartmental Physical Sciences

2008

APPENDIX III ASSESSMENTS

APPENDIX III A
PRETEST FOR THE THERMODYNAMICS UNIT

1. Look at the drawing below to answer the questions that follow.

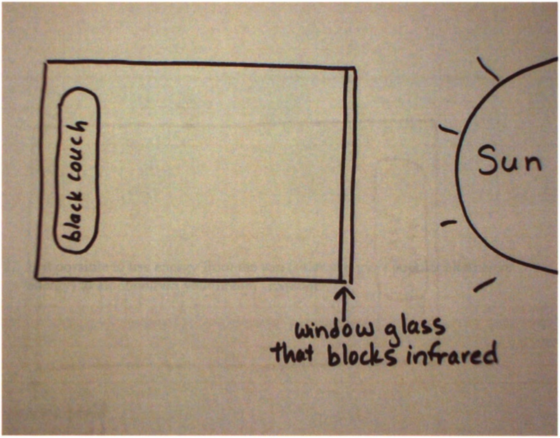


Figure 8 Solar Space (teacher's drawing)

a) Draw arrows representing the wavelengths of light that are transmitted, reflected, absorbed or emitted by each object.

b) How would the diagram be different if it was night time?

c) If you wanted to experiment with making the room hotter or cooler, what sorts of parameters could you vary and test? What do you expect to happen to each and why?

2. Is it possible to use energy from the sun (solar energy, a popular alternative energy) to air condition your home? Explain?

3. What determines the amount of work you can get out of a heat engine?

4. What term means "a substance's ability to store heat"? What formula is used to calculate its value?

5. There is a solar collector on your roof heating water for your swimming pool.

    a) Circle three areas where there is temperature change due to heat transfer.

    b) Identify the two substances that are coming into contact in each area that you circled. Just write the words beside the circle.

    c) What equation would you use to determine the final temperature when substances of two different temperatures come into contact?

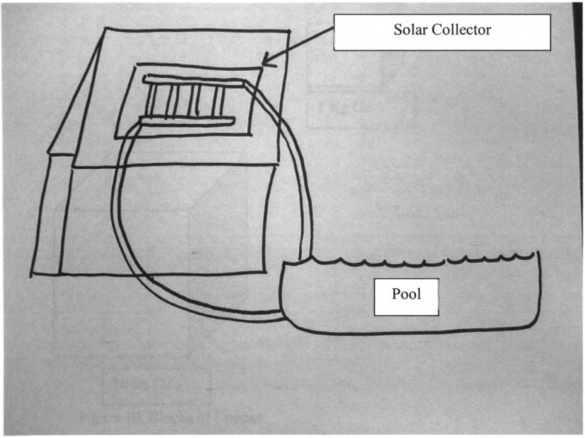


Figure 9 Solar Heated Pool (teacher drawing)

6. Describe a scenario with familiar objects that illustrates thermal equilibrium. Comment on heat flow and temperature.

7.

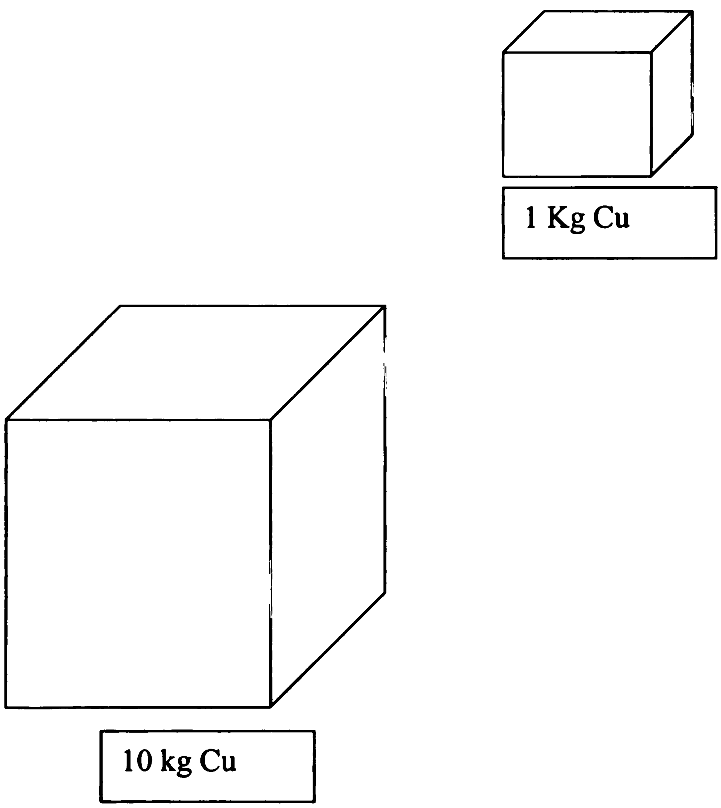


Figure 10 Blocks of Copper

If both blocks of copper are experiencing the same environmental conditions, which would have a

a) higher temperature?
Why?

b) greater thermal energy?
Why?

1. Look at the drawing below to answer the questions that follow.

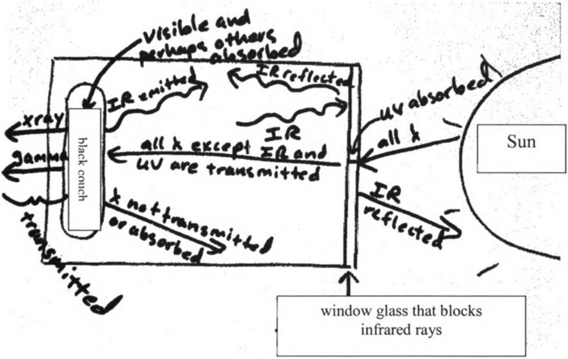


Figure 11 Solar Space Answer Key (teacher's drawing)

a) Draw arrows representing the wavelengths of light that are transmitted, reflected, absorbed or emitted by each object.

See drawing above.

b) How would the diagram be different if it was night time?

No wavelengths would enter the room, thus none transmitted and none absorbed.

c) If you wanted to experiment with making the room hotter or cooler, what sorts of parameters could you vary and test? What do you expect to happen to each and why?

i) Changing the color of the couch. I would expect the room to be cooler if the couch was white instead of black because fewer wavelengths would be absorbed and later emitted as heat.

ii) Using glass that does not block infrared rays. I would expect the room to be cooler as the IR emitted by the couch would escape rather than build up.

2. Is it possible to use energy from the sun (solar energy, a popular alternative energy) to air condition your home? Explain?

   Yes. You could use a geothermal heat pump, or a Stirling engine could generate electricity which could power an air conditioner.

3. What determines the amount of work you can get out of a heat engine?

   The difference in temperature between the hot and cold reservoirs.

4. What term means "a substance's ability to store heat"? What formula is used to calculate its value?

   Specific Heat (C) **$C = Q/m\Delta T$**

5. There is a solar collector on your roof heating water for your swimming pool.

   a. Circle three areas where there is temperature change due to heat transfer.

   b. Identify the two substances that are coming into contact in each area that you circled. Just write the words beside the circle.

   c. What equation would you use to determine the final temperature when substances of two different temperatures come into contact?

$$\mathbf{mC\Delta T = -(mC\Delta T)}$$

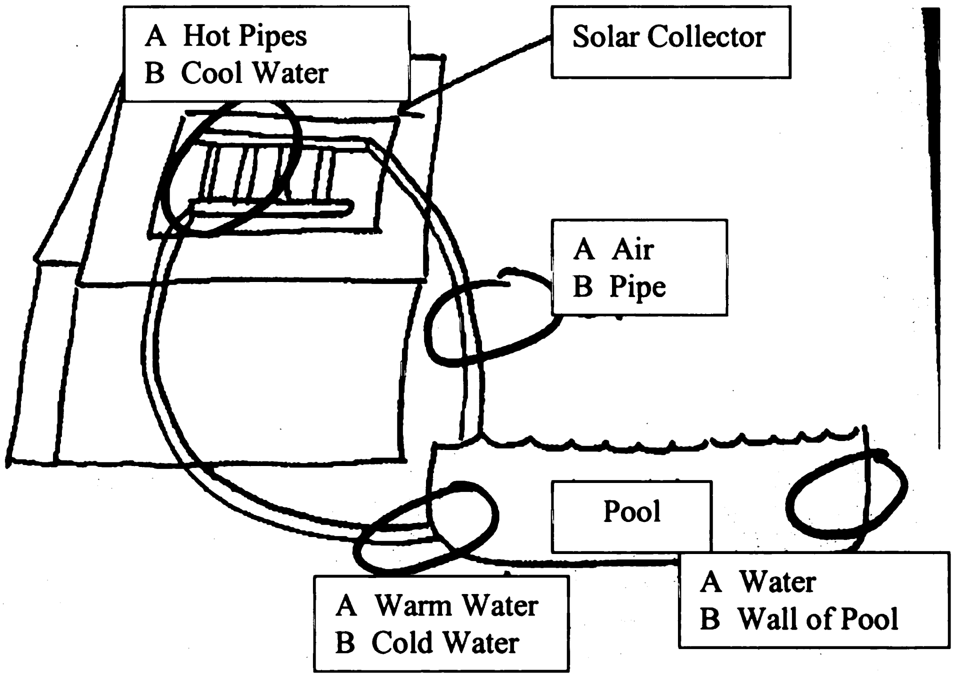


Figure 12 Solar Heated Pool Answer Key (teacher's drawing)

6. Describe a scenario with familiar objects that illustrates thermal equilibrium. Comment on heat flow and temperature.

   A sick child has a thermometer under his tongue. Heat flows from the hot tongue to the thermometer until their temperatures are equal. At that point there is an equal amount of heat flowing from the tongue to the thermometer as from the thermometer to the tongue.

7.

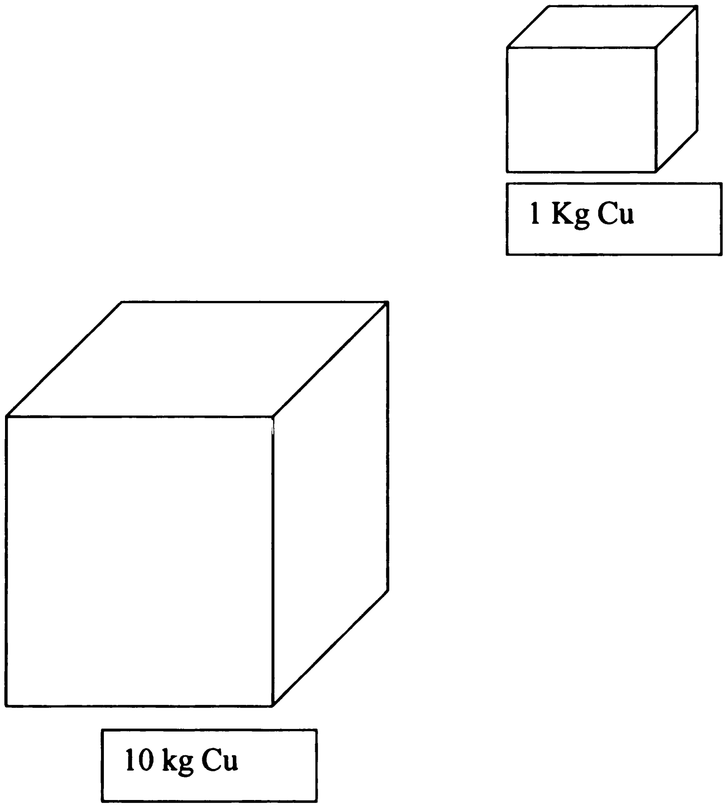


Figure 13 Two Blocks of Copper

If both blocks of copper are experiencing the same environmental conditions, which would have a

c) higher temperature? **Neither.**
   Why? **Temperature is the average kinetic energy of the particles. The particles in both would have the same average kinetic energy.**

d) greater thermal energy? **The 10-kg block**
   Why? **It contains more particles and thermal energy is the sum of the kinetic energy in all of the particles.**

APPENDIX III B
THERMODYNAMICS POST TEST

Note that the post test was embedded into the regular unit test. Questions 1-15 were part of the unit test, but were not part of the post test, and so are not shown below.

16. What property measures a substance's ability to store heat?
    What formula is used to calculate its value?

17.

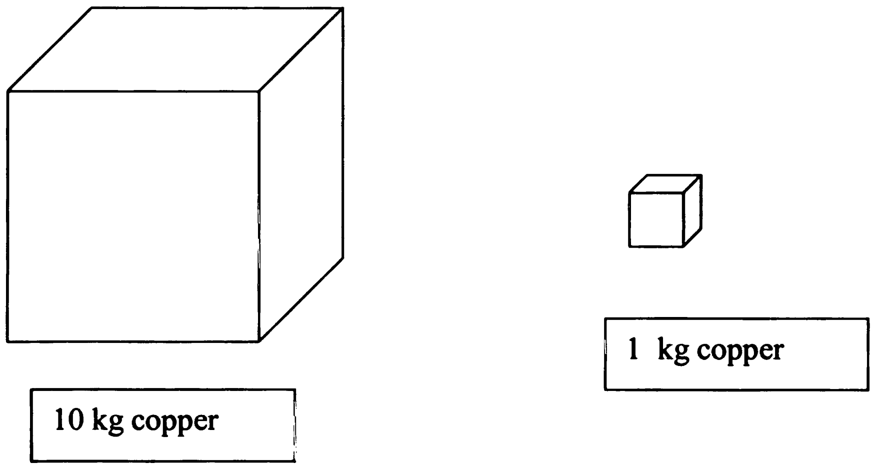


Figure 14 Copper Blocks of Different Masses

If both blocks are experiencing the same environmental conditions, which would

a) have a higher temperature?

b) have a greater thermal energy?

19. Is it possible to use solar energy to air condition your home? Explain.

20. Draw the type of solar hot water system that is safest to use in Michigan.

a) Circle 3 areas where there is temperature change due to heat transfer.

b) What equation would you used to calculate final temperature when substances of two different temperatures come into contact?

c) Identify substance A and substance B in each of the 3 circled areas.

21. Draw a labeled (side view) diagram of a solar room during the day. Assume the glazing is normal window glass that has also been treated so that it is not transparent to infrared. Your drawing should include arrows that are labeled to show which wavelengths they represent.

a) How would the diagram above be different if it was night?

b) What would be different if the absorber was yellow?

c) What would be different if the glazing did not block infrared?

22. Thinking of the little rockets we built, state 3 questions you may have about the rockets' performance that could be investigated in an empirical manner.

23. Pick one of the questions in 22 above and very briefly describe how you would test it. Be sure to identify the variable and describe your control.

24. Draw a labeled diagram of a Stirling engine.

a) Tell how it relates to the topic of alternative energy.

b) What determines the amount of work you can get out of any heat engine?

TEACHER'S KEY FOR THE THERMODYNAMICS POST TEST

1. What property measures a substance's ability to store heat? **Specific Heat**
   What formula is used to calculate its value?

   $$C = Q/m\Delta T$$

2.

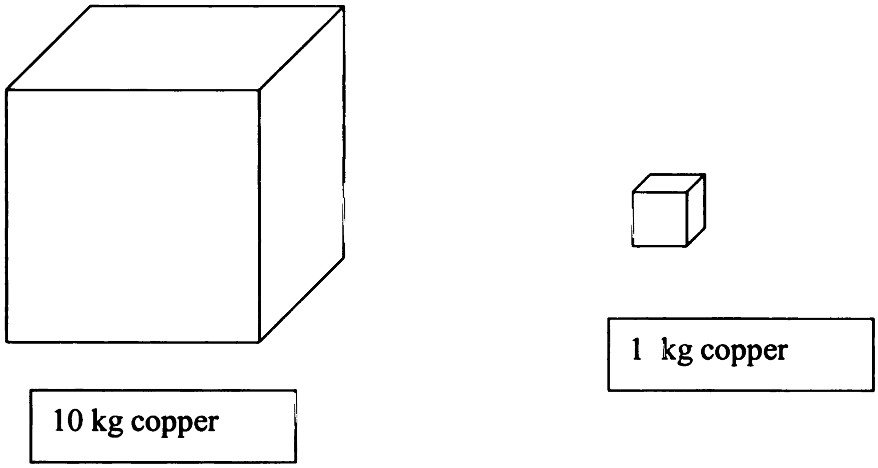


Figure 15 Copper Blocks

If both blocks are experiencing the same environmental conditions, which would

a) have a higher temperature? **Neither. The average kinetic energy of the particles in both is equal.**

b) have a greater thermal energy? **The larger block. Thermal energy is the sum of the kinetic energy of the particles in the block. There are more particles in the larger box so the sum is larger.**

3. Describe a scenario in an alternative energy system which illustrates thermal equilibrium. Comment on heat flow and temperature.

   A sick child has a thermometer under his tongue. Heat flows from the hot tongue to the thermometer until their temperatures are equal. At that point there is an equal amount of heat flowing from the tongue to the thermometer as from the thermometer to the tongue.

4. Is it possible to use solar energy to air condition your home? Explain.

Yes. You could use a geothermal heat pump, or a Stirling engine could generate electricity which could power an air conditioner.

5. Draw the type of solar hot water system that is safest to use in Michigan.

   a. Circle 3 areas where there is temperature change due to heat transfer. **Note that I circled four. The students only need to circle three.**

   b. What equation would you used to calculate final temperature when substances of two different temperatures come into contact?
   $mC\Delta T = -(mC\Delta T)$

   c. Identify substance A and substance B in each of the 3 circled areas.

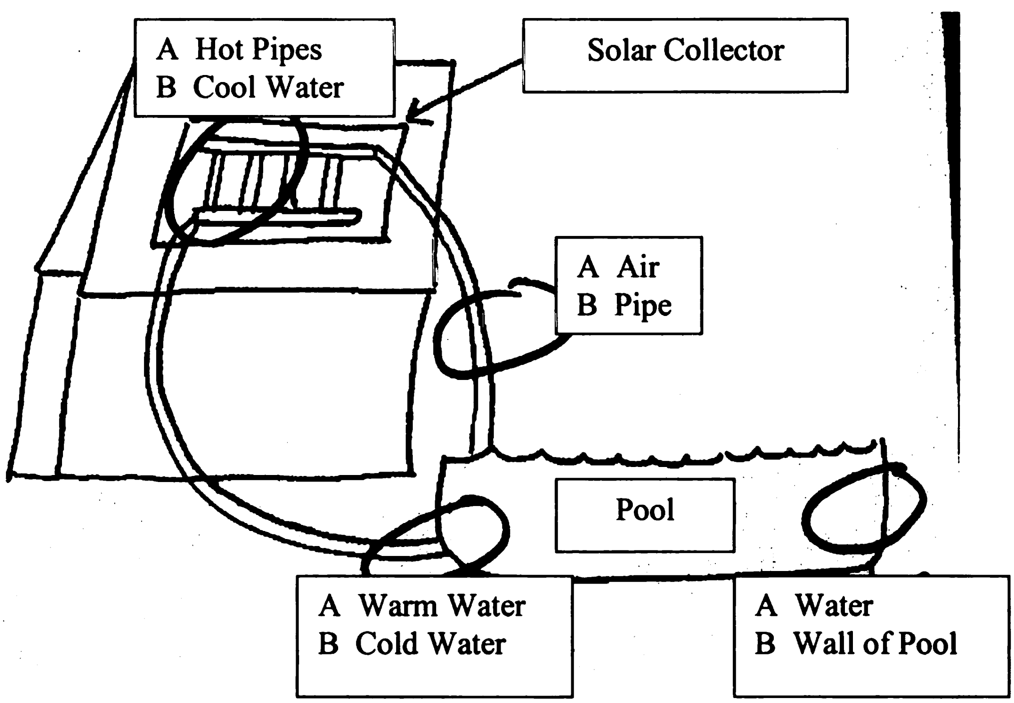


Figure 16 Solar Heating System for a Pool (teacher's drawing)

6. Draw a labeled (side view) diagram of a solar room during the day. Assume the glazing is normal window glass that has also been treated so that it is not transparent to infrared. Your drawing should include arrows that are labeled to show which wavelengths they represent.

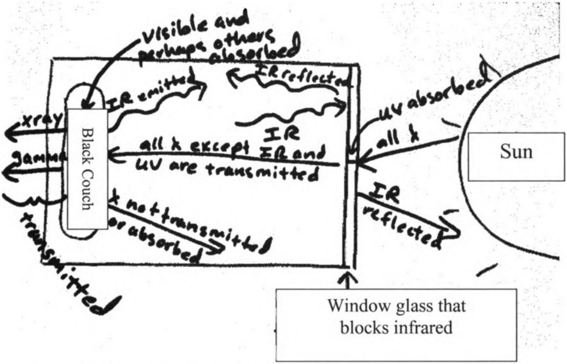


Figure 17 Solar Room Answer Key (teacher's drawing)

a) How would the diagram above be different if it was night?
No wavelengths would enter the room, thus none transmitted and none absorbed.

b) What would be different if the absorber was yellow?
Fewer of the visible wavelengths would be absorbed by the couch and re-emitted as infrared (heat) so the room would be cooler.

c) What would be different if the glazing did not block infrared?

I would expect the room to be cooler as the IR emitted by the couch would escape rather than build up.

7. Thinking of the little rockets we built, state 3 questions you may have about the rockets' performance that could be investigated in an empirical manner.

Any answers that make sense are ok. Here are some possibilities:
Is there a relationship between the number of match heads and distance?
Would heavy duty foil affect the tendency to tear?
Would heavy duty foil influence the time it takes to ignite the match?
Does diameter of the tail pipe affect flight distance?
Does length of the tail pipe affect flight distance?

8. Pick one of the questions in 22 above and very briefly describe how you would test it. Be sure to identify the variable and describe your control.

The possibilities are unlimited, but be sure the student has only one variable and a control, and that the procedure will really test the hypothesis and yield empirical data. Example: To test whether there is a relationship between diameter of the tail pipe and flight distance, two sizes of paper clips and a hanger could be used. Make 25 rockets using jumbo paper clips, 25 using regular paper clips, and 25 using a section of a wire clothes hanger. Measure the distance each travels after ignition. Multiple rockets of the same tailpipe diameter serve as the control. Calculating the variation in those will show the amount of variance inherent in your method. Comparing the average distance flown between the three groups will show a relationship between the variable of tailpipe diameter and distance flown. Only the difference that is greater than the inherent variance is significant.

9. What determines the amount of work you can get out of any heat engine?

The difference in temperature between the hot and cold reservoirs determines the amount of work that you can get.

APPENDIX III C
THERMODYNAMICS AND OPTICS UNIT
RAW DATA FROM PRETEST AND POST TEST
ANALYZED BY BENCHMARK

Note that 13 students took the Pretest while only 12 took the Post Test.

1. Look at the drawing below to answer the questions that follow.

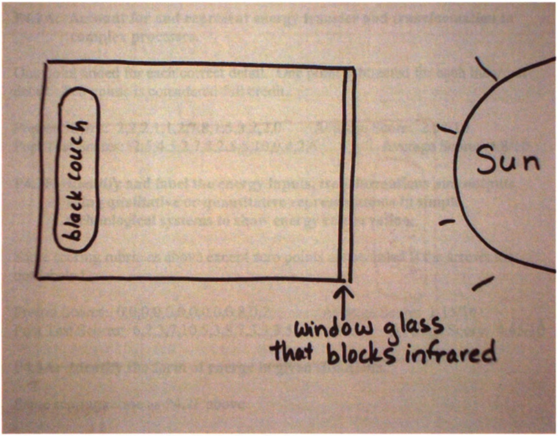


Figure 18 Solar Room (teacher's drawing)

a) Draw arrows representing the wavelengths of light that are transmitted, reflected, absorbed or emitted by each object.

P4.1A: Account for and represent energy into and out of systems using energy transfer diagrams.

One point added for each correct detail. One point subtracted for each incorrect detail. Ten points is considered full credit.

Pretest Scores: 2,3,3,5,7,2,2,2,1,0,2,2,1 Average Score: 2.46/10
Post Test Scores: 2.5,4.5,2,7,8,2.5,5,10,9,4,2,6 Average Score: 4.8/10

P4.1B: Explain instances of energy transfer by waves and objects in everyday activities.

One point added for each correct detail. One point subtracted for each incorrect detail. Ten points is considered full credit.

Pretest Scores: 7,2.5,3,8,2,2,1,2,2,1,0,2 Average Score: 2.65/10
Post Test Scores: 2.5,4.5,2,7,8,2.5,5,10,9,4,2,6 Average Score: 4.8/10

P4.2A: Account for and represent energy transfer and transformation in complex processes.

One point added for each correct detail. One point subtracted for each incorrect detail. Ten points is considered full credit.

Pretest Scores: 2,2,2,1,1,2,7,8,1.5,3,2,2,0 Average Score: 2.58/10
Post Test Scores: 2.5,4.5,2,7,8,2.5,5,10,9,4,2,6 Average Score: 4.8/10

P4.2F: Identify and label the energy inputs, transformations and outputs using qualitative or quantitative representations in simple technological systems to show energy conservation.

Same scoring rubric as above except zero points are awarded if the arrows are not labeled.

Pretest Scores: 0,0,0,0,0,0,0,0,0,0,8,0,7 Average Score: 1.15/10
Post Test Scores: 6,2,3,7,10,5,3,8,7,3,3,3.5 Average Score: 4.65/10

P4.3A: Identify the form of energy in given situations.

Same scoring rubric as P4.2F above.

Pretest Scores: 0,0,0,0,0,0,0,0,0,6,8,0,0, Average Score: 1.08/10
Post Test Scores: 6,2,3,7,10,5,3,8,7,3,3,3.5 Average Score: 4.65/10

P4.5A: Identify everyday examples of energy transfer by waves and their sources.

Same scoring rubric as P4.2A above.

Pretest Scores: 2,2,7,1,1,2,8,1,1,0,2,2,2 Average Score: 2.38/10
Post Test Scores: 2.5,4.5,2,7,8,2.5,5,10,9,4,2,6 Average Score: 4.65/10

P4.6h: Explain the relationship between the frequency of an electromagnetic wave and its technological uses.

Same scoring as P4.2F above.

Pretest Scores: 0,0,0,0,0,0,0,0,0,0,0,8,7 Average Score: 1.15/10
Post Test Scores: 6,2,3,7,10,5,3,8,7,3,3,3.5 Average Score: 4.65/10

P4.8A: Draw ray diagrams to indicate how light reflects off objects or refracts into transparent media.

Five points for reflecting at correct angle, 2.5 for reflecting at incorrect angle, 5 for refracting at any angle.

Pretest Scores: 0,2.5,2.5,2.5,5,5,5,2.5,2.5,2.5,2.5,2.5,3
Average Score: 2.96/10
Post Test Scores: 0,10,2.5,?,7.5,2.5,5,?,5,2.5,0,5 (Two responses were illegible.)
Average Score: 5.0/10

P4.8B: Predict the path of reflected light from flat, curved or rough surfaces.

10 points for correct angle of reflection off flat surface. Points are subtracted if are some at incorrect angles.

Pretest Scores: 0,0,0,10,10,0,4,5,0,10,0,0,0 Average Score: 3.0/10
Post Test Scores: 0,5,0,?,0,0,5,?,5,0,0,5 Average Score: 2.0/10

b) How would the diagram be different if it was night time?

P4.2A: Account for and represent energy transfer and transformation in complex processes.

10 points if student mentioned IR was emitted by the couch. 5 points for waves being absorbed but not transformed and re-emitted. One point if they communicate transfer or transformations that are incorrect.

Pretest Scores: 5,1,1,0,1,1,10,10,10,10,10,5,5 Average Score: 5.31/10
Post Test Scores: 5,2,7.5,10,?,10,?,1,?,2,10,? Average Score: 5.94/10

P4.2f: Identify and label the energy inputs, transformations and outputs using qualitative or quantitative representations in simple technological systems to show energy conservation.

Five points if show IR still being given off. 2.5 points for showing IR reflecting back in as it hits glazing. 2.5 points if show no waves entering.

Pretest Scores: 5,2,10,10,10,10,10,2,10,0,10,5,5 Average Score: 6.85/10
Post Test Scores: ?,10,10,?,0,10,10,0,10,0,0,0 Average Score: 4.00/10

c) If you wanted to experiment with making the room hotter or cooler, what sorts of parameters could you vary and test? What do you expect to happen to each and why?

The Post Test question was different: Thinking of the little rockets we built, state three questions you may have about the rockets' performance that could be investigated in an empirical manner. Pick one of the questions and briefly describe how you would test it. Be sure to identify the variable and the control.

P1.1F: Predict what would happen if the variables, methods or timing of the investigation were changed.

Five points for each prediction whether plausible or not. Ten points maximum.

Pretest Scores: 0,10,0,5,5,0,10,5,5,10,5,10,10 Average Score: 5.77/10
Post Test Scores: 10,?,10,?,?,?,?,10,?,?,6.6,? Average Score: 9.15/10

P1.2j: Apply science principles or scientific data to anticipate effects of technological design decisions.

Five points for each prediction that is based on sound science principles from this unit. Subtract five points for each unsound predictions. Maximum score is 10 points.

Pretest Scores: 0,10,0,5,0,0,7.5,5,5,5,5,5,0 Average Score: 3.65/10
Post Test Scores: 10,?,10,?,?,6.6,10,3.3,?,10,10,? Average Score: 8.56/10

P1.1A: Generate new questions that can be investigated in the laboratory or field.

Award 3.3 points for each variable that would have an effect and could be tested. Maximum 10.

Pretest Scores: 3.3,10,3.3,0,0,0,3.3,0.6.6,6.6,6.6,6.6,3.3 Average Score: 3.82/10
Post Test Scores: ?,10,3.3,10,3.3,10,10,10,3.3,6.6,6.6,6.6 Average Score: 7.25/10

2. Is it possible to use energy from the sun (solar energy, a popular alternative energy) to air condition your home? Explain?

P4.2A: Account for and represent energy transfer and transformations in complex processes.

Ten points if explanation is completely correct. Two points if they just say yes. Two more points if they say solar energy could power an air conditioner.

Pretest Scores: 2,2,10,0,0,2,2,2,5,2,2,2,2 Average Score: 2.54/10
Post Test Scores: ?,2,1,?,5,2,5,?,?,0,?,10 Average Score: 3.57/10

P4.2B: Name devices that transform specific types of energy into other types.

Five points for devices named with correct type of energy transformations.
One points for devices named with incorrect type of energy transformations.

Pretest Scores: 1,0,10,0,5,5,0,5,5,5,0,5,0 Average Score: 3.15/10
Post Test Scores: ?,5,0,5,5,0,5,?,?,0,?,5 Average Score: 3.13/10

3. What determines the amount of work you can get out of a heat engine?

P4.2C: Explain how energy is conserved in common systems.

Ten points for a completely correct answer. Partial credit for a partially correct answer.

Pretest Scores: 0,0,0,0,0,0,1,0,0,0,5,5,0 Average Score: 0.85/10
Post Test Scores: 10,10,1,10,10,10,0,10,10,10,10,0 Average Score: 7.58/10

P4.2D: Explain why all the stored energy in gasoline doe not transform to the mechanical energy of a vehicle.

Same scoring as above.

Pretest Scores: 0,0,0,0,0,0,1,0,0,0,5,5,0 Average Score: 0.85/10
Post Test Scores: 10,10,1,10,10,10,0,10,10,10,10,0 Average Score: 7.58/10

4. What term means "a substances ability to store heat"? What formula is used to calculate its value?

P4.11b: Calculate the final temperature of two liquids.

Two points for the correct term. Eight points for the correct equation.

Pretest Scores: 0,0,0,0,0,0,0,0,0,0,0,0,0 Average Score: 0.0/10
Post Test Scores: 8,10,10,10,0,10,10,8,8,8,0,2 Average Score: 7.0/10

5. There is a solar collector on your roof heating water for your swimming pool.

   a. Circle three areas where there is temperature change due to heat transfer.

   b. Identify the two substances that are coming into contact in each area that you circled. Just write the words beside the circle.

   Benchmarks for a and b: P4.1A, P4.1B, P4.2A: descriptions of all were listed previously.

   Parts a and b were scored together as one. One point for a circle with no labels, but possibly correct placement. Two points for a circle with correct placement and one substance labeled. 3.3 points for a circle of proper placement with both substances properly labeled.

   Pretest Scores: 1,6,3,0,3,0,4,0,3,0,5,5,3
   Average Score: 2.54/10
   Post Test Scores: 4,3,3,5.33,3,7.33,3,3,3,1,6.33,3
   Average Score: 3.75/10

   c. What equation would you use to determine the final temperature when substances of two different temperatures come into contact?

   Benchmark P4.11b: the description was listed previously.

   Ten points for the correct answer. Zero points for an incorrect answer.

   Pretest Scores: 0,0,0,0,0,0,0,0,0,0,0,0,0
   Average Score: 0.0/10
   Post Test Scores: 10,10,10,10,10,10,10,10,10,10,10,0
   Average Score: 9.17/10

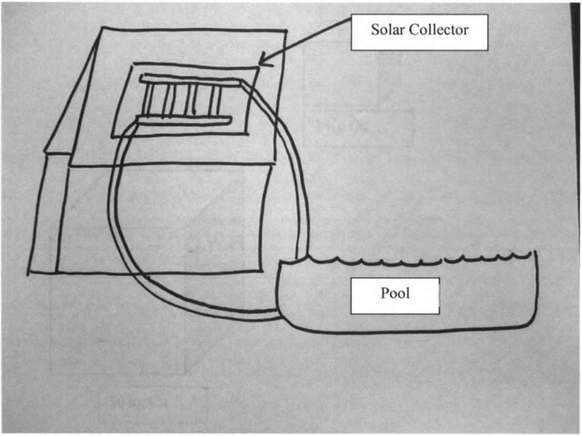


Figure 19 Solar Pool (teacher's drawing)

6. Describe a scenario with familiar objects that illustrates thermal equilibrium. Comment on heat flow and temperature.

   Benchmarks P4.1B, P4.2A, P4.2C: descriptions were listed previously.

   Correct scenario is worth 3.33 points. Correct heat flow is worth 3.33 points. Correct comments on temperature are worth 3.33 points.

   Pretest Scores: 0,0,0,0,0,0,0,0,3.33,0,0,3.33,3.33
   Average Score: 0.77/10
   Post Test Scores: 3.33,3.33,3.33,6.66,0,0,0,3.33,6.66,3.33,3.33,3.33
   Average Score: 3.05/10

7.

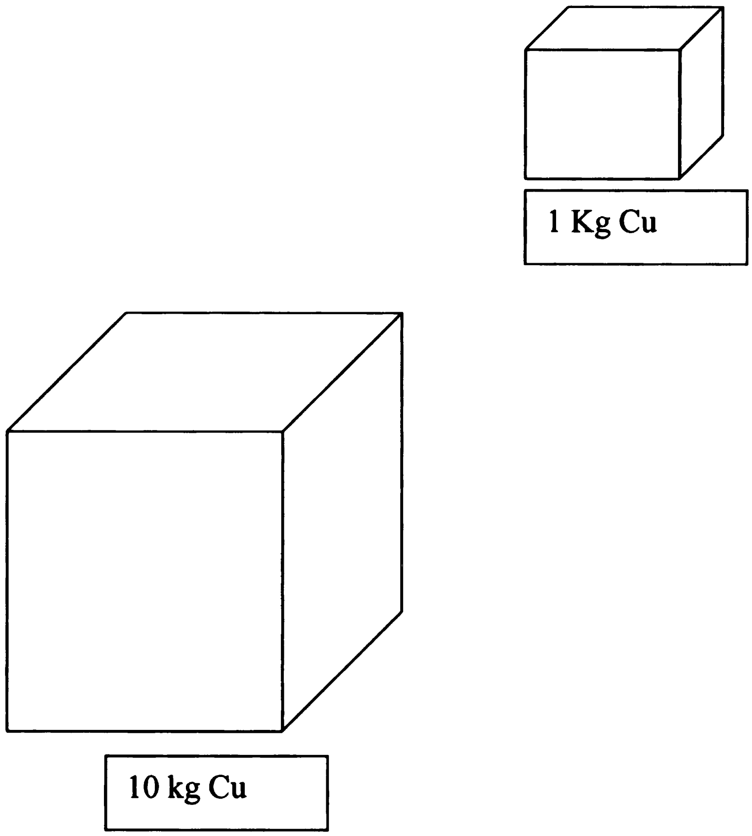


Figure 20 Copper Blocks with Different Masses

If both blocks of copper are experiencing the same environmental conditions, which would have a

e) higher temperature?
Why?

f) greater thermal energy?
Why?

There are no current benchmarks in the state of Michigan that directly address the difference between thermal energy and temperature, but it is background for understanding P4.11b whose description was listed earlier.

Five points for choosing the correct block in part a. Five points for choosing the correct block in part b.

Pretest Scores: 5,5,5,5,0,5,0,0,0,0,0,0,0 Average Score: 1.92/10
Post Test Scores: 10,10,5,5,10,5,5,5,10,5,10,0 Average Score: 6.67/10

APPENDIX III D
ITEM ANALYSIS OF PRETEST AND POST TEST QUESTIONS
FOR THE THERMODYNAMICS UNIT

Because most of the questions were open-ended and required a student generated written response, the scoring was quite subjective. I scored both the pretest and the post test twice. The second scoring occurred about eight weeks after the first. The second time I wrote out a simple rubric beside each question and followed it closely. As the first scoring was done without a rubric, only the data from the second scoring is used in the analysis below.

Question 1a covered so many benchmarks that on the second scoring I broke it up into four separate scores, lumping similar benchmarks together.

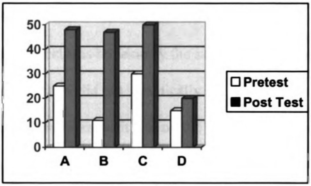


Figure 21 Question 1a Scores as Percentages

Letter	Benchmark Category	Probability of Outcome
A	Energy Transfer and Transformation	0.010, 0.036, 0.019
B	Identify or Label Energy Transfer/Transformations	0.002, 0.011, 0.049, 0.002
C	Ray Diagrams	0.309 (insignificant gain)
D	Path of Reflected Light	0.824 (insignificant gain)

Table 7 Legend and T-test P Values for Question 1a

Question 1b covered three categories of benchmarks as listed below.

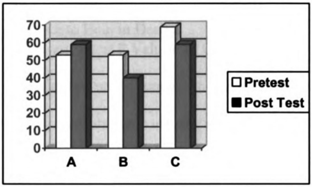


Figure 22 Question 1b Scores as Percentages

Letter	Benchmark Category	Probability of Outcome
A	Energy Transfer	0.653 (insignificant gain)
B	Form of Energy	0.653 (insignificant loss)
C	Inputs, Transformations, Outputs, Conservation	0.290 (insignificant loss)

Table 8 Legend and T-test P Values for Question 1b

Question 1c on the pretest was not exactly the same as the corresponding question on the post test. On the post test I did not specifically ask for a prediction, but included points for predictions on the rubric as it was on the rubric for the prior knowledge question. There may be students who would have given a prediction if asked outright.

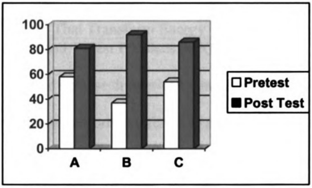


Figure 23 Question 1c Scores as Percentages

Letter	Benchmark Category	Probability of Outcome
A	Generating Questions	0.043
B	Predictions When Parameter is Varied	0.048
C	Apply Science to Help in Design	0.014

Table 9 Legend and T-test P Values for Question 1c

On the pretest, the variables and predictions given were comparable to elementary school knowledge. Multiple students made use of the concept that black absorbs heat and white reflects it. On the post test the variables and predictions were more sophisticated and many related to their new knowledge of heat engines.

Question 2 did not specifically ask students to name devices, but I considered the naming of them as an important part of a mastery level response for this question.

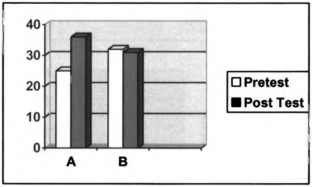


Figure 24 Question 2 Scores as Percentages

Letter	Benchmark Category	Probability of Outcome
A	Energy Transfer and Transformation	0.741 (insignificant gain)
B	Name Devices That Transform Energy	0.763 (insignificant loss)

Table 10 Legend and T-Test P Values for Question 2

Although the scores did not rise dramatically, the explanations changed. In the pretest, all of the answers that were correct referred to solar energy being converted to electricity (or in half of these cases "solar energy powers the air conditioner".) The only device mentioned was a solar panel. And none of the answers demonstrated knowledge of how the solar energy was converted to electricity.

On the post test I had expected explanations that incorporated geothermal heat pumps, (utilizing the sun to heat the hot reservoir) and Stirling engines (again using the sun's heat for the hot reservoir). Out of 12 students, two named geothermal heat pumps, two others said heat engines. And one named the Stirling engine. Interestingly, two of the students gave answers that made no sense while all of the answers in the pretest made sense. Perhaps all of the new information had been ingested, but not digested. That is, not processed to the point where it was understood and integrated into existing knowledge.

Data from **Question 3** showed a phenomenal improvement from pretest to post test.

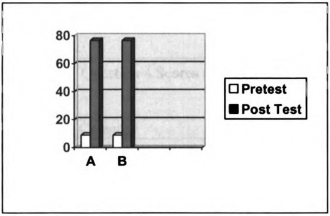


Figure 25 Question 3 Scores as Percentages

Letter	Benchmark Category	Probability of Outcome
A	Energy Conservation	0.001
B	Why Not All the Energy in Gasoline is Converted to Mechanical Energy	0.001

Table 11 Legend and t-Test P Values for Question 3

It is quite probable that the students knew something about energy conservation before the unit, but had no idea what a heat engine was. The increase in knowledge is significant. And even if the low prior knowledge score was due to ignorance of the heat engine, learning about it is essential for understanding thermodynamics. The fact that the amount of work you can get out is determined by the difference in temperature is knowledge needed to work toward mastery of energy conservation benchmarks. It is also essential for understanding how various alternative energy systems work, such as the geothermal heat pumps or the Stirling engines which can utilize concentrated solar energy for their hot reservoir.

Question 4 addressed only one benchmark as shown below.

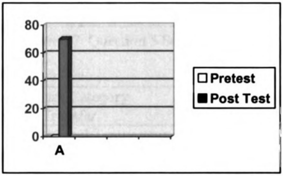


Figure 26 Question 4 Scores as Percentage

Letter	Benchmark Category	Probability of Outcome
A	Calculating Final Temperature of Two Mixed Liquids	0.000

Table 12 Legend and T-Test P Value for Question 4

The new physics benchmarks assume that students already know the basics of specific heat capacity from taking chemistry. In light of the data above, I will continue to teach specific heat in my physics classes even though it is no longer a part of the physics benchmarks. The students cannot understand the calculations of the final temperature if they don't understand specific heat. In my opinion, there is no point to students performing calculations that they don't understand.

Question 5 was broken into 2 categories of benchmarks for the purpose of scoring. Benchmark A goes with question parts 2a and 2b, while benchmark B goes with question 2c.

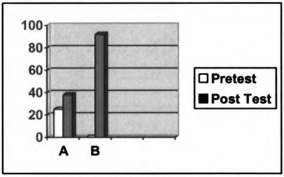


Figure 27 Question 5 Scores as Percentages

Letter	Benchmark Category	Probability of Outcome
A	Energy Transfer	0.175 (insignificant gain)
B	Calculate Final Temperature of Two Mixed Liquids	0.000

Table 13 Legend and T-Test P Values for Question 5

The comparison of pretest to post test scores for this question is based on slightly different questions. On the pretest, they were given a diagram of the system, and on the post test the students had to draw a labeled diagram of a closed-loop solar hot water system. On the pretest the students could demonstrate some knowledge of heat transfer without understanding how a solar water heating system works. As an example, they could have circled an area where pool water meets air as a location of heat transfer. Scoring in such a case should be based on whether there is heat transfer occurring at the place the student circled, and not on whether the drawing of the system was accurate.

Note that part c in question 5 "What equations would you use..." required memorization only, while parts a and b required higher order thinking.

Question 6 on the pretest just asked the student to illustrate thermal equilibrium with familiar objects, whereas the post test question required their example to be an alternative energy system.

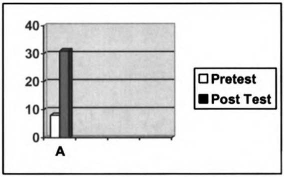


Figure 28 Question 6 Scores as Percentages

Letter	Benchmark Category	Probability of Outcome
A	Energy Transfer and Energy Conversion	0.002

Table 14 Legend and T-Test P Value for Question 6

Very few students demonstrated that they knew that the amount of heat flowing from A to B equals the amount flowing from B to A. Only one student out of 13 mentioned that the temperatures of the two objects were equal. Physics benchmarks don't mention thermal equilibrium. It is another case of knowledge that should have been learned in Chemistry class so that it can be applied to scenarios in Physics class. Next year I will need to make time to teach the concept before I try to have them apply it to physical scenarios.

Question 7 on the pretest asked "why", but the corresponding question on the post test did not. I realized this after I had scored the prior knowledge responses, so went back and changed the rubric to ignore the "why" responses and rescored the question.

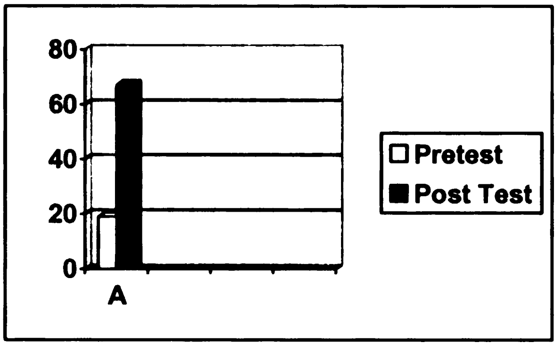


Figure 29 Question 7 Scores as Percentages

Letter	Benchmark Category	Probability of Outcome
A	Calculate the Final Temperature of Two Liquids	0.002

Table 15 Legend and T-Test P Values for Question 7

The difference between heat and temperature is also no longer addressed in the physics benchmarks. It is assumed that the students already know the concept. Again, this is not the case. But it is a crucial distinction for understanding the calculation of final temperatures of two liquids that are mixed together. Many students are so ignorant of the difference that they do not distinguish between the two and insert a temperature value for Q instead of a heat value, or a use a heat value for ΔT. I did spend extra time with students on this distinction and it seemed to be somewhat effective as evidenced by the data above.

APPENDIX III E
THERMODYNAMICS POST SURVEY

1. What did we do in this chapter that really engaged you? Explain.

2. What did we do in this chapter that was boring? Explain.

3. What did you learn that you are likely to remember a long time or make use of in the future?

4. Why do you think the items you listed in #3 above ended up being the things you will remember or make most use of?

THERMODYNAMICS POST SURVEY
EXAMPLES OF STUDENT WORK

Student responses have been typed in as the handwriting was not dark enough to be legible after scanning.

Unit 2 – Post Survey

1. What did we do in this chapter that really engaged you? Explain.

   I actually enjoyed building different solar collectors and learning how they actually work, and how many different variables there are when building one. Besides, I like making things.

3. What did we do in this chapter that was boring? Explain.

   Boiling water lab. I didn't think that I learned much more doing a lab that took a day, in notes that would take ten minutes.

4. What did you learn that you are likely to remember a long time or make use of in the future?

   How a solar collector basically works.

5. Why do you think the items you listed in #3 above ended up being the things you will remember or make most use of?

   It is interesting to me, and if I ever own my own house I think I would like my home to be mainly solar powered.

Unit 2 – Post Survey

1. What did we do in this chapter that really engaged you? Explain.

   The rockets and the different experiments.

2. What did we do in this chapter that was boring? Explain.

   The different reading sections/articles. They seemed tedius.

3. What did you learn that you are likely to remember a long time or make use of in the future?

   How to make a rocket and how to make my home more energy efficient.

4. Why do you think the items you listed in #3 above ended up being the things you will remember or make most use of?

   Rockets are sweet. I will remember how to make my house more energy efficient energy because I like to save money and help the environment.

Unit 2 – Post Survey

1. What did we do in this chapter that really engaged you? Explain.

   I liked doing the labs. I would rather learn hands-on then by reading a book.

2. What did we do in this chapter that was boring? Explain.

   I hate doing in-book homework.

3. What did you learn that you are likely to remember a long time or make use of in the future?

   Maybe if I go into a field where I would need to know about heating & solar energy it would be useful.

6. Why do you think the items you listed in #3 above ended up being the things you will remember or make most use of?

   I think probably b/c we did labs on them and I was most interested in them.

RAW DATA FROM THERMODYNAMICS POST SURVEY

1. What did we do in this chapter that really engaged you? Explain.

   Design Your Own Solar Collector Experiment was mentioned by 5 students.
   Student Comments:
   Learning how the collectors actually work.
   Learning how many different variables there are when building.
   I like making things.
   Because we were up and moving.
   It was difficult yet still allowed you to get a good understanding of solar energy.
   If we can design something that really saves energy and money it would be _______ . (Illegible)
   It really puts our learning to real life problems.
   It was fun.
   It helped strengthen my lab procedure and write-up.

   The Rockets were mentioned by 2 students. None added comments.

   The Labs were mentioned by 4 students.
   Student Comments:
   Would rather learn hands-on. (Two students wrote this comment.)
   I really learned a lot.

   Absorption Lab was mentioned by 1 person. No comments were written.

2. What did we do in this chapter that was boring? Explain.

   Articles were mentioned by 5 students.
   Student Comments:
   Quite dull.
   Didn't help my understanding of thermodynamics.
   Never really caught my interest.
   It was still early in the morning and hard to focus on reading.
   They seemed tedious.
   Math Problems were mentioned by 2 students.
   Student Comments:
   They are just work, not learning.
   The long equations were so repetitive.

   Reading was mentioned by 1 student. No comments were written.

Boiling Water Lab was mentioned by 1 student.
Student Comments:
Could have learned as much in notes that would take 10 minutes instead of taking the day.

In-Book Homework was mentioned by 2 students.
Student Comments:
I hate it.

All Homework was mentioned by 1 student. There were no comments.

Most Labs was mentioned by 1 student. There were no comments.

Notes were mentioned by 1 student. There were no comments.

3. What did you learn that you are likely to remember a long time or make use of in the future?

How a Solar Collector Works was mentioned by 3 students.
Student Comments:
The structure of a plate collector.
How an absorber plate and manifolds affect the overall performance.

How to Make a Rocket was mentioned by 2 students.
Student Comments:
And how rockets work.

How to Make My House More Energy Efficient was mentioned by 2 students.
There were no student comments.

Heating and Solar Energy were mentioned by 1 student.
Student Comments:
Maybe if I go into a field where I would need to know about heating and solar energy it would be useful.

How a Geothermal Heat Pump Works was mentioned by 2 students.
Student Comments:
The heat pumps.
Hot and cold reservoir.

Not a Whole Lot was mentioned by 1 student.
Student Comments:
Because what I am going to do has nothing to do with this.

How People Use Alternative Energy was mentioned by 1 student.
There were no student comments.

How Many Resources and Money Alternative Energy Saves was mentioned by 1 student. There were no student comments.

4. Why do you think that the items you listed in #3 above ended up being the things you will remember or make most use of?

Fun was mentioned by 2 students.
Student Comments:
It was fun making solar collectors.

Creative was mentioned by 1 student. There were no student comments.

Contributing Data to the Scientific Community was mentioned by 1 student. There were no student comments.

The Online Research was mentioned by 1 student. There were no student comments.

Real Life Problem was mentioned by 1 student. There were no student comments.

They are Sweet was mentioned by 1 student.
Student Comments:
(He was referring to the rockets.)

Cool That We Are Finding Different Ways to Use Energy was mentioned by 1 student. There were no student comments.

Because I was Most Interested in Them was mentioned by 2 students. There were no student comments.

Something I Can Use in the Future was mentioned by 3 students.
Student Comments:
Because in everyday life I won't need to know what specific heat is or how to calculate heat changes and phase changes.
If I ever own my own house I think I would like my home to be solar powered.

I Don't Know was mentioned by 1 student. There were no student comments.

Hands-on was mentioned by 2 students.
Student Comments:
I usually remember things such as labs or projects, basically anything that requires me using a lot of physical energy.
Because we did labs on them.

Because I Like to Save Money was mentioned by 1 student.
Student Comments:
1 – Because I like to help the environment.

ANALYSIS OF THERMODYNAMICS POST SURVEY DATA

The first question on the Post Survey asked, "What did we do in this chapter that really engaged you?" Six of the responses named activities that involved alternative energy. Four just said, "the labs". Some labs involved alternative energy and some did not. Two of the responses were for an activity that did not involve alternative energy. All twelve responses, however, were for hands-on activities.

The second question asked, "What did we do in this chapter that was boring? Explain." Six of the responses had to do with readings and five with math or homework. Two had to do with labs and one named notes. Five of the above-mentioned definitely involved alternative energy, three or four could have, but the responses were not specific enough to pinpoint the specific activity. Two definitely did not involve alternative energy. Two of the above responses were hands-on and twelve were not hands-on.

"What did you learn that you are likely to remember a long time or make use of in the future?" Ten responses involved alternative energy and two did not. Two of the responses mentioned information they may have gotten through hands-on activities and/or drawings, one from drawings, math and or notes, two from the readings and one from an internet search homework assignment. Three could not be classified in the above manner.

The last question asked "Why do you think the items you listed in #3 above ended up being the things you will remember or make the most use of?" Six responses fall into a category I'm calling "fun/creative/interesting/cool/sweet" as those were the descriptors students used. Six responses had to do with the information being useful. Two said it was because it was learned in a hands-on manner. One student cited being able to contribute to the scientific community.

Overall, the students in this class reported hands-on activities as the ones that they found most engaging. One hundred percent of the students named a hands-on activity as the one that most engaged them. And at least half of those responses had to do with alternative energy.

When naming things in the unit that they found boring, most named more passive activities. Only two of the activities named were hands-on. Five of the activities mentioned as boring involved alternative energy.

Things the students were likely to remember, or use, favored alternative energy concepts ten to two. The ways the information was obtained were varied with no clear pattern or single effective method emerging.

Student responses as to why they would remember, or use, those particular concepts were split. Six declared that the information or activity was fun or interesting and six claimed that it was, or would be, useful.

It appears that hands-on activities are more engaging regardless of the topic. The topic seems to make a slight difference. A little more than half of the positive responses related to the topic of alternative energy and a little less than half of the negative responses related to the topic. Although with such a small data set, the margin of error would erase that difference.

Whether or not the student judges the information to be useful, seems to carry as much weight as whether they found the information interesting or fun. So perhaps teachers need to put more energy into communicating the ways that concepts will be useful to the student.

CRITIQUE OF THE THERMODYNAMICS POST SURVEY METHOD

Student responses to questions number one and two were consistent with each other. If a student found hands-on activities engaging, it would make sense that they found more passive activities boring. When the teacher thinks of engagement, she envisions a student's brain involved in critical and creative thinking, with many new connections being made to previous knowledge and things in the student's everyday life. The student's idea of engagement may be just having a lot of fun physically manipulating equipment without out really engaging the brain in rigorous learning. In retrospect, I think I should have discussed my definition of engagement with the students. But I don't know if they would have been able to objectively discern between the two.

I am also not convinced that a teacher should worry too much about whether a student finds an activity boring. Only one student mentioned the boiling water lab as boring on the survey, but almost all of them voiced it as we were doing the lab. However, even though the students find it boring, most don't forget that temperature does not change during the phase change. They recall their frustration of staring at a thermometer whose reading seemed to be magically stuck at the same temperature as the minutes ticked by.

One important drawback of giving such a survey at the end of a long unit, is that things that occurred toward the end of the unit are more easily recalled than things that happened near the beginning. It probably skews the data quite a bit. If I do this sort of data collection again, I will read through the old lesson plans aloud before they fill out the survey to remind them of all of the earlier activities.

There is another point worth considering. Do students really know which things they will remember a long time or make use of in the future? Regardless, their belief could still give insight into why they put effort into learning some concepts and not others.

For responses that were too general for me to accurately catalog, it would have been helpful to interview the students soon after to get a more specific response. An accurate categorization of a larger percentage of the data would have resulted in more accurate interpretation.

Many of the things students believe they will remember a long time were things we learned in multiple ways. Thus it is not possible to ascertain if it was the labeled drawings that clicked with them, their interest in the particular topic of alternative energy, the hands-on building, the detailed readings, or just the fact that we learned the material in multiple ways. A larger data set would have been helpful here. But an even better option would be to devote a whole thesis to investigating this question.

APPENDIX III F
THERMODYNAMICS AND OPTICS UNIT
STUDENTS' ENGAGEMENT REPORTS

SAMPLES OF STUDENTS' ENGAGEMENT DATA

Each student looked around the classroom once per day and observed the number of students that appeared to be engaged. . He included himself in the data. On a piece of paper the student would record the date, time, number of students that seem to be engaged, number that do not seem to be engaged and the activity the students were supposed to be participating in. This was done to help me collect data for this thesis. Student engagement was used as a measure of motivation.

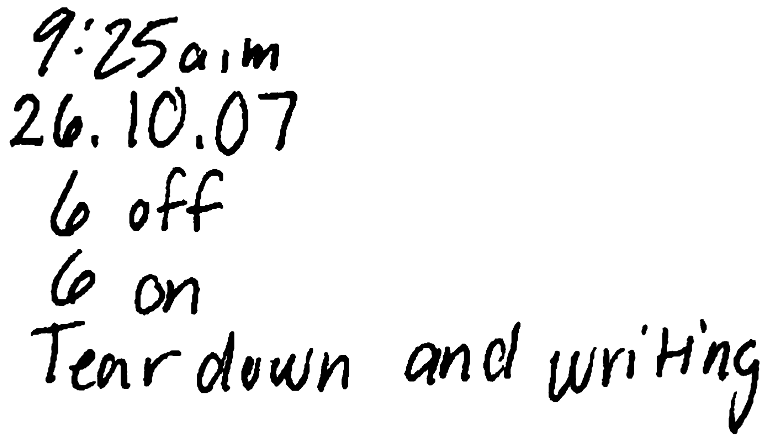
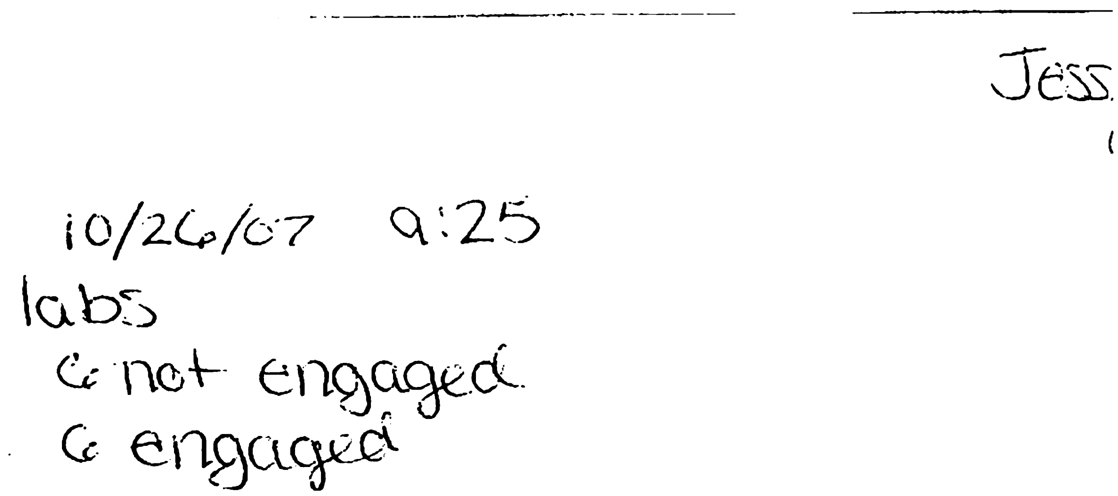

9:25a.m
26.10.07
6 off
6 on
Tear down and writing

Figure 30 Example 1 of Student Engagement Data Report

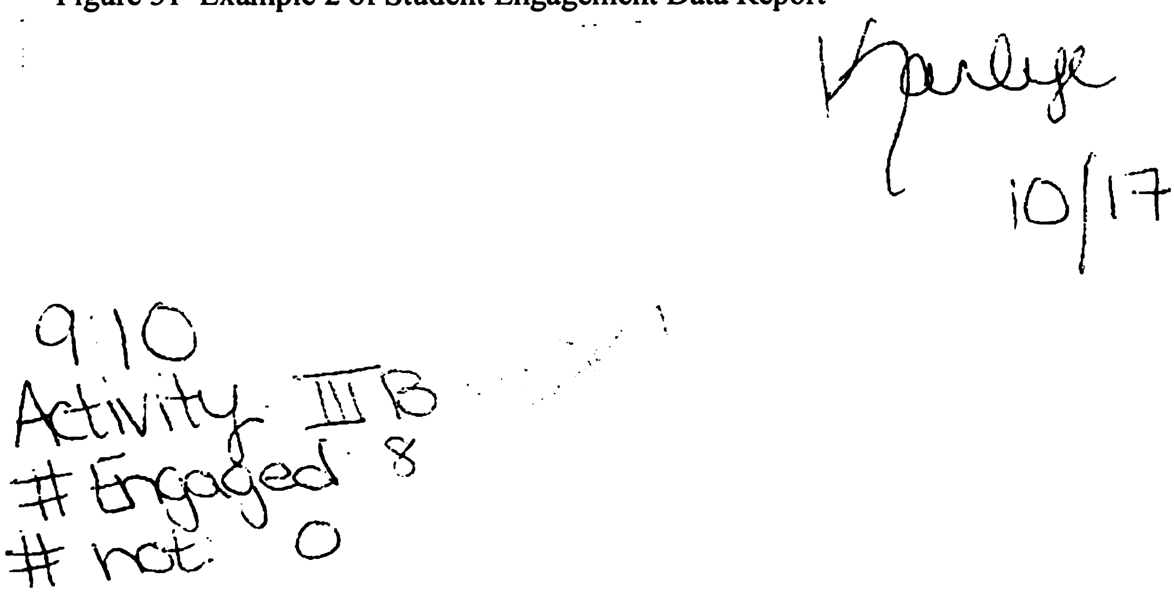
Notice that the sample above and below were taken at the same time. The one above is a little more descriptive than the one below, but I still had to look at their data immediately after class and make notes to myself as to exactly what we were doing at the time.



Jess.

10/26/07 9:25
labs
6 not engaged
6 engaged

Figure 31 Example 2 of Student Engagement Data Report



10/17

9:10
Activity IIIB
Engaged 8
not 0

Figure 32 Example 3 of Student Engagement Data Report

This is another typical sample of engagement data collected by students. My notes to the side did not show up when scanned, but were to tell me what she meant by "Activity IIIB". We were filling in the drawing on the objective sheet under IIIB which was the solar hot water system.

THERMODYNAMICS AND OPTICS UNIT
RAW COMPILED DATA ON STUDENT ENGAGEMENT

Students gathered engagement data every day during the unit. However, on days that the students were totally immersed, some forgot to record their observations. This is a compilation of the data that was collected.

Type of Activity	Students on Task	Students off Task	Percent of Students on Task
Writing Homework Assignment in Planner	27	4	87%
Watching a Video	76	22	78%
Labeled Drawing-Type Notes	310	30	91%
Taking Regular Notes	449	32	93%
Taking a Homework Quiz	72	0	100%
Class Discussion	20	4	83%
Filling in Vocabulary Terms on Study Guide	128	14	90%
Background Questions on Lab	50	2	96%
Highlighting as Instructor Reads	9	2	82%
Physically Working on a Lab	448	49	90%
Watching a Demonstration	36	0	100%
Going over a Test	76	17	82%
Taking a Test	70	0	100%
Oral Presentation of Lab Results	13	9	59%
Planning and Designing an Experiment	21	1	95%
Going Over a Lab	73	16	82%
Taking the Prior Knowledge Survey	11	0	100%
Working on Math Problems	136	46	75%
Doing Post Lab Questions	12	0	100%
Going Over Homework	133	20	87%
Working on Qualitative Bellwork	22	0	100%
Filling in Answers on a Packet	95	5	95%
Listening While Instructor Reads	16	6	73%
Instructor Explaining The Lab	8	3	73%
Scoring Notebook of Daily Work	11	0	100%
Silent Reading	8	16	33%
Students Reading Aloud	54	3	95%
Going Over a Packet Assignment	20	2	91%
Watching a Slide Show	10	2	83%
Math Review	18	6	75%
Cleaning Up After An Experiment	39	9	81%
Working on a Lab Write-Up	18	6	75%
Organizing Notebook of Daily Work	59	0	100%

Table 16 Raw Engagement Data by Activity Type

Activity Category	Students on Task	Students off Task	Percent of Students on Task
Tests, Quizzes, Grading Notebooks and Writing Down Homework Assignments	587	13	98%
Physical Activities: Labs, Class Discussions, Planning Labs, Cleaning up After Labs	349	51	87%
Non-Physical Activities: Notes: 92% on Task Silent Reading: 33% on Task Reading Aloud: 95% on Task Working on Math Problems: 75% on Task	1908	392	83%

Table 17 Engagement Data Summarized by Activity Type

Table 18 below lists only alternative energy activities and Table 19 lists all others.

Date	Activity	On Task	Off Task	Percentage of Students on Task
9/27	Homework Quiz	13	0	100%
9/28	Labeled Drawing of Solar Hot Water System on Lab	20	5	80%
9/28	Specific Heat Lab Background Questions	11	2	85%
9/28	Going Over Background Questions on Solar Collectors	13	0	100%
10/2	Highlighting Parts in Articles on Solar Heating	9	2	82%
10/3	Filling in on the Absorbance and Emission Lab Packet	12	0	100%
10/3	Notes on Emission and Absorption in Solar Rooms	22	0	100%
10/3	Filling in Drawing of Emission, Absorption, Transmission on Study Guide	9	2	82%
10/5	Performing Absorbance Lab	11	0	100%
10/8	Notes: What is Expected on Absorbance Lab Conclusion	27	8	77%
10/12	Photovoltaic Packet Questions	11	2	85%
10/12	Geothermal Heat Pump Drawing	22	4	85%
10/12	Stirling Engine Drawing	17	9	65%
10/16	Drawing of Flat Plate Collector	10	1	91%

Table 18 Raw Engagement Data for Alternative Energy Activities

Date	Activity	On Task	Off Task	Percentage of Students on Task
10/16	Notes to Help Fill in Design Your Own Solar Collector Experiment	11	0	100%
10/17	Planning Experiment for Design Your Own Solar Collector Experiment	21	1	95%
10/17	Drawing Solar Hot Water System on Study Guide	8	0	100%
10/25	Constructing Solar Collectors for Their Experiments	39	0	100%
10/26	Cleaning up the Experiments and Starting Lab Write-Up	57	15	79%
10/29	Presenting Lab Results to Peers	13	9	59%

Table 18 Continued

Date	Activity	On Task	Off Task	Percentage of Students on Task
9/27	Filling in Vocabulary Terms on Study Guide	38	14	73%
10/4	Writing Down Homework Assignment	8	1	89%
10/4	Notes on $mC\Delta T = mC\Delta T$	11	0	100%
10/9	Working on Math Problems on $Mc\delta t$	18	8	69%
10/10	Notes on Heat of Fusion and Heat of Vaporization	40	15	73%
10/10	Boiling Water Lab	33	2	94%
10/11	Going Over Math Homework	44	5	90%
10/11	Notes on First Law and Heat Engines	12	0	100%
10/11	Taking Homework Quiz on Heats of Fusion and Vaporization	35	0	100%
10/12	Homework Quiz on Heat Engines and Refrigerators	13	0	100%
10/15	Instructor Explains Rocket Construction	8	3	73%
10/15	Silent Reading on Entropy	0	12	0%
10/15	Reading Aloud on Thermodynamics	8	3	73%
10/15	Constructing Rockets	33	33	100%

Table 19 Raw Engagement Data for Other Activities

10/16	Going Over Follow-Up Questions on Rockets (Heat Engines)	10	1	91%
10/18	Math Review	28	20	58%
10/23	Going Over Math Homework	19	5	79%

Table 19 Continued

Activity Category	Students on Task	Students off Task	Percent of Students on Task
Alternative Energy	356	60	86%
Alternative Energy but Removing Taking Tests and Quizzes, Scoring Notebooks and Writing Down Homework Assignments	343	60	85%
Other Than Alternative Energy	358	122	75%
Other Than Alternative Energy but Removing Taking Tests and Quizzes, Scoring Notebooks and Writing Down Homework Assignments	302	121	71%

Table 20 Summary of Engagement Data

ANALYSIS OF THERMODYNAMICS ENGAGEMENT DATA

When listing engagement data by activity, the activities seem to represent three major categories. Activities that are traditionally used for assessment, and that students associate with lots of points, included taking tests and quizzes, organizing and scoring notebooks of daily work and writing down homework assignments in planners. The data showed that when we were doing any of these types of activities, students were focused on the task 98% of the time. Most physics students care about their grade-point average, so this level of engagement is not surprising.

The rest of the categories were split into two groups, physical activities and non-physical activities. The physical activities included labs, class discussion, planning labs and cleaning up after labs. The students' data indicated 87% engagement while doing these sorts of activities. This figure is probably skewed quite low. I noticed that on days when the students were most engaged, many forgot to gather engagement data. The missing data would have indicated high percentages of engagement. With that data totally missing, it is hard to say what it might have been, but it certainly would have pushed the engagement up above 87%.

The third category included everything not already assigned to one of the first two categories. It included things like taking notes, reading silently, reading aloud and working on math problems. Even though the students complain the loudest every time we take notes, 92% of them are engaged during those times. Possibly that is because it is so easy to take notes. The student doesn't even have to think. It can just go in one ear and out through the hand. The brain of some students must be on automatic pilot. I do continually ask questions throughout my lectures in an attempt to keep the brain actively involved and to give them opportunity to construct some knowledge even when taking notes.

Silent reading received the lowest engagement score, 33%. I feel it is important to include silent reading and important to force students to read critically and carefully to figure things out themselves from a reading. According to the data, it looks like students would be more engaged in silent reading if it was tied to an assignment that was worth points. And from my experience, it is crucial to grade them on accuracy, not just completion.

An alternative way to classify the activities that has more to do with the thesis statement of this project, sorts them by whether or not they involve alternative energy.

When split up in this way, the data at first glance seems to show that activities incorporating alternative energy result in a higher level of engagement, 85% and 86% compared to 71% and 75%.

However, after also compiling the data from the Electricity unit, there appears to be no difference unless the traditional assessment sorts of activities are removed. Activities incorporating alternative energy and those not incorporating it both showed engagement of 90%. But after removing tests, quizzes, scoring notebooks and writing down homework assignments, there was a significant difference. The students' data then showed 88% engagement for the alternative energy activities and 70% for the activities not involving alternative energy. This makes sense as most of the tests, quizzes, scoring of notebooks and writing down homework assignments were in the category that did not involve alternative energy. This relationship also agrees with the data compiled on the Thermodynamics unit only.

THERMODYNAMICS AND OPTICS UNIT CRITIQUE OF THE METHOD OF STUDENTS GATHERING ENGAGEMENT DATA

From general day to day observations, which I wrote down in a journal, having students collect these data may not have been a reliable or accurate method. When we started the unit, students were instructed to look around the room at some random time of their choosing. They were to write down how many students appeared to be engaged in the assigned task, how many appeared not to be engaged, the date, the time, and a short description of the assigned task.

One problem was that students would often leave out part of the information, quite often it was what the assigned task was. If they had written the time, I could usually figure out what the activity might have been, but I had to throw out quite a bit of data due to being unsure of the task. I got in the habit of looking through the data for that day immediately after class was over, while I could still remember what we did and when we did it. I wrote little notes of my own near their notation of the activity to make it more descriptive so that I could make better use of it later. Small preprinted forms with a space for activity/task, time, date, number of engaged and number not engaged might have been a good idea. The students just wrote their data on scraps of blank notebook paper.

Having students gather the data at random times may have led to a second problem: skewed data. The student would probably be more likely to think of observing the room to collect engagement data when he himself was bored and not engaged.

By the end of the second week of the unit so few students were turning in the data, that I assigned them each a specific time to collect data. They also made themselves little reminder cards with their assigned time to set out on their desks at the beginning of each class. This also solved the problem of students being more likely to collect data during periods of low engagement.

By the end of the fourth week so few students were turning in data that I told them it would be worth one point per day. Participation went way up, but it is likely to have exacerbated the existing problem of faulty data. Several times I observed students who were assigned a time earlier in the hour, quickly jotting data down at the end of the period and handing it in. There were even two instances of students writing it down the following day and trying to turn it in. I am guessing that the student forgot to look around the room at the assigned time and just wrote down any numbers that came to mind in order to turn the data in for a point.

Early on I observed another serious problem with this method of gathering data. When activities really engaged the students fully, and they were immersed all hour, they would forget to take data even with constant reminders from me. This was especially true when the students were constructing solar collectors. This results in data being skewed way to the low side.

And finally, quite often my observations did not match up at all with the data that was turned in that day. If I had struggled to get and keep their attention while going over homework, students were still turning in data showing that almost all of the students were engaged during that time.

On the positive side, this method does result in a lot of very specific data. Although, if that data is faulty, what good is it? It was also my original feeling that students might be better judges of the level of engagement of other students than a teacher would be. Perhaps if the student was really scrutinizing the behavior like a teacher does, they might be better at it since their thought patterns may be more like the other students'. But the students gathering data didn't really have a reason to pay close enough attention to accurately assess the level of involvement. It is similar to a business owner not being able to find employees that care as deeply about the health of his business as he does.

One detail essential for making this method work at all is that the teacher write little notes on the packet of data sheets the students turn in every day. The notes should be things that will help her remember exactly what each activity entailed. The lesson plan book does not give enough specific information to result in an accurate correlation of dates and times with activities. If a student describes an activity or task as "class discussion", the teacher should fill in what the topic was.

APPENDIX III G
ELECTRICITY PRETEST

1. Name devices that transform chemical energy to electrical energy.

2. Name a device that transforms light energy to electrical energy.

3. Name devices that transform mechanical energy to electrical energy.

4. Draw an example of a closed (complete) circuit.

5. Draw the same circuit, except show it as open instead of closed.

6. If a light bulb was included in the circuits above, in which circuit, if either, would the bulb be lit?

7. Explain the following terms as they relate to the circuits you drew:

   Voltage

   Resistance

   Current

8. Draw a simple battery and tell how it works.

9. If you wanted to increase the voltage output of a solar panel, would you connect the individual solar cells in series or in parallel? Explain.

10. If the lights on your Christmas tree were wired in series, what would happen when one of them burned out? Explain.

TEACHER'S KEY FOR THE ELECTRICITY PRETEST

1. Name devices that transform chemical energy to electrical energy.
   Battery, fuel cell

   Benchmark P4.10B. It goes with question 16 on the unit test.

2. Name a device that transforms light energy to electrical energy.
   Photovoltaic cell (solar cell)

   Benchmark P4.10B. It goes with question 16 on the unit test.

3. Name devices that transform mechanical energy to electrical energy.
   Wind turbine, water turbine, hand-crank generator

   Benchmark P4.10B. It goes with question 16 on the unit test.

4. Draw an example of a closed (complete) circuit.

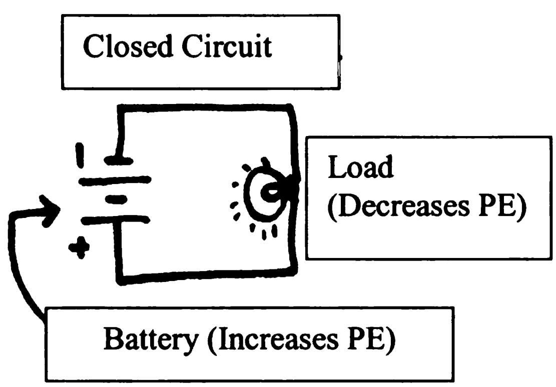


Figure 33 Closed Circuit (teacher's drawing)

Benchmark P4.10C. It goes with question 12 on the unit test.

5. Draw the same circuit, except show it as open instead of closed.

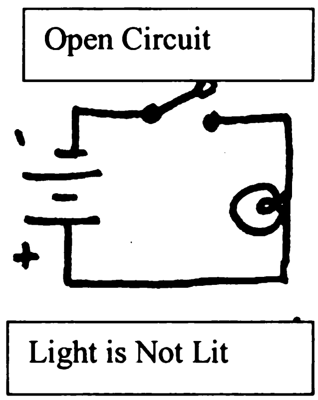


Figure 34 Open Circuit (teacher's drawing)

Benchmark P4.10C. It goes with question 11 on the unit test.

6. If a light bulb was included in the circuits above, in which circuit, if either, would the bulb be lit?
   The bulb would be lit in the closed circuit.

   Benchmark P4.10C. It goes with question 11 on the unit test.

7. Explain the following terms as they relate to the circuits you drew:

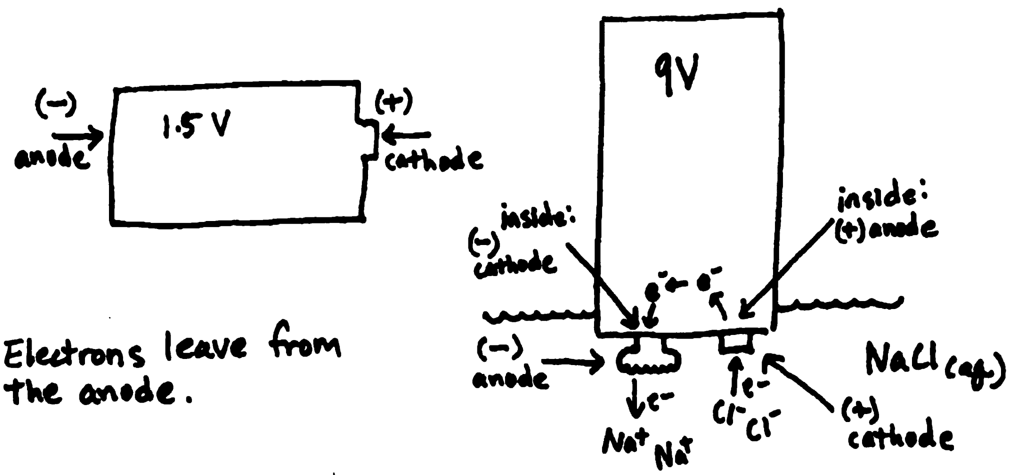
   Voltage: **The push behind the flowing electrons. (How bad they want to get to the positive terminal.) Or, the difference in potential between the positive and negative terminals.**

   Resistance: **The tungsten filament in the bulb is hard for electrons to flow through. The friction of them trying to get through creates heat and light.**

   Current: **Electrons flowing through the wire**

   Benchmark P4.10D. It goes with question 11 on the test.

8. Draw a simple battery and tell how it works.



$Na^+ + e^- \rightarrow$ Na (reduced) $2Cl^- \rightarrow Cl_2 + 2e^-$ (oxidized)

Figure 35 Batteries and How They Work (teacher's drawing)

When discharging, the electrons are produced at the anode and flow through the load toward the cathode. An electrolyte inside the battery provides the electrons.

Benchmark P4.10C and P4.10B. It goes with question 17 on the unit test.

9. If you wanted to increase the voltage output of a solar panel, would you connect the individual solar cells in series or in parallel? Explain.
You would connect it in series because their voltages would add together. (In a parallel circuit there is more than one path to take so the initial pressure is split between the available paths.)

Benchmark P4.10g. It goes with question 18 on the unit test.

10. If the lights on your Christmas tree were wired in series, what would happen when one of them burned out? Explain.

All of the lights in the strand would go out. The circuit is incomplete. There is only one path to follow and that path got a break in it.

Benchmark P4.10g. It goes with question 19 on the unit test.

COMMENTS ON RAW DATA FROM THE ELECTRICITY PRETEST

Consult Appendix III H for pretest data. It is found in the section titled Analysis of Raw Data From Pretest and Post Test.

1. Name devices that transform chemical energy to electrical energy.
   (Benchmark P4.10B)

All students but one were already able to name at least one device that transforms chemical energy to electrical. Seven students listed the battery. Three students listed the power plant which contains several devices, none of which transform chemical energy directly into electricity. Two mentioned car engines which transform chemical energy to mechanical rather than to electrical. I think perhaps some students consider everything under the hood of a car as part of the engine. There is a device under the hood, the alternator, whose main function is to transform mechanical to electrical energy.

One student evidently did not know the meaning of device, or wasn't reading carefully, and listed processes such as stirring, heating, and speeding up the chemical process. None of those processes are related to the question.

In light of their responses, students lacked knowledge of fuel cells and needed to learn the details of energy transformations occurring in power plants and car engines. Five of the twelve students need to learn that batteries transform chemical energy to electrical energy.

2. Name a device that transforms light energy to electrical energy.
   (Benchmark P4.10B)

The data suggests that students do not know the function of a solar collector (to collect electromagnetic waves and transform non-infrared frequencies to infrared). It doesn't generate electricity.

In current literature, solar panel usually refers to a flat plate collector. Flat, plate-shaped photovoltaic cells are usually referred to as modules, but are occasionally called solar panels.

Students need to become familiar with the terms photovoltaic and solar cell. They need to learn the function of solar collectors contrasted with the function of photovoltaics. Explaining the way the term solar panel is currently used is also in order.

3. Name devices that transform mechanical energy to electrical energy.
   (Benchmark P4.10B)

Students who listed pulley and wedge as devices that perform this transformation must not know the meaning of the terms mechanical energy and electrical energy. They need to learn those concepts and also what an energy transformation is. Six of the eleven students who took the prior knowledge survey need to learn what a generator is and how it functions. Ten of the eleven need to be exposed to turbines and their function. They should also be make aware that there are water turbines as well as wind and steam turbines. The data indicates that time should also be devoted to the function of engines and the electric car.

4. Draw an example of a closed circuit.
   (Benchmark P4.10C)

Students need to learn the structure and function of a battery, the three requirements of a closed circuit (continuous loop, charge pump and potential difference) and the conventions for schematic drawings.

5. Draw the same circuit, except show it as open instead of closed.

It appears that ten of the eleven already know that an incomplete circuit has a break in the conducting loop. Therefore, not much time should be spent on this.

6. If a light bulb was included in the circuits above, in which if either, would the bulb be lit?
(Benchmark P4.10C)

Since nine of the eleven students realize that a bulb in an incomplete circuit will not light, little time should be devoted to this concept.

7a. Explain the following terms as they relate to the circuit you drew: voltage, resistance, and current.
(Benchmark P4.10D)

Of the three terms, voltage is the one the students know the least about. So the most time should be spent on that one. Most students can communicate the concepts of resistance and current in a qualitative manner. Time spent on those two should be devoted to their quantitative aspects.

8. Draw a simple battery and explain how it works.
(Benchmark P4.10C and P4.10B)

Most students realize that a battery has a positive and a negative terminal. Some students have a vague idea of how a battery functions. Others have no idea. Sufficient time should be spent on this topic so that students can make a labeled drawing which includes distributions of charge. They should be able to relate steps in its function to the transformation of chemical to electrical energy.

9. If you wanted to increase the output of a solar panel, would you connect the individual cells in series or parallel? Explain.
(Benchmark P4.10g)

Seven of the eleven students chose the correct response of "series", but none gave a correct explanation. Therefore, it will be important to spend time on the differences in voltage and current in a series as opposed to a parallel circuit.

10. If the lights on your Christmas tree were wired in series, what would happen if one of them burned out? Explain.
(Benchmark P4.10g)

Nine students knew they would all go out. Two students thought they might all burn out. One of those said "If one breaks, they all break". The other may not know that burning out means that the filament breaks in two. Only three students gave the correct explanation for their answer. I need to devote time to the structure of a light bulb and the function of the filament. Close attention should be paid to contrasting the flow of electrons when there is a complete for them to travel and when there is a break in that loop. I need to clarify the difference between a bulb that is burned out and a bulb that is not receiving electricity.

APPENDIX III H
ELECTRICITY POST TEST

Note that the post test questions used to gather data for this thesis were imbedded within the Unit 3 Test. Only the portion of the test that contained the post test questions is shown below.

10. What is the difference between voltage, resistance and current?

11. Draw a schematic of an open circuit that contains a battery, a resistor and a bulb. Label each component. Would the bulb be lit?

12. Draw a schematic of a closed circuit that contains a light bulb, a battery and a voltmeter.

13. Could an ammeter be put in the circuit above in the same place the voltmeter is shown? Explain.

16. Name devices that transform

    a) chemical energy to electrical energy

    b) mechanical energy to electrical energy

    c) light energy to electrical energy

17. Draw a labeled diagram of a simple battery and explain how it works.

18. If you wanted to increase the voltage output of a solar panel, would you connect the individual solar cells in series or in parallel? Explain.

19. What is the benefit of having Christmas tree lights wired in parallel instead of series?

TEACHER'S KEY FOR THE ELECTRICITY POST TEST

Note that the post test questions used to gather data for this thesis were imbedded within the Unit 3 Test. Only the portion of the test that contained the post test questions is shown below.

10. What is the difference between voltage, resistance and current?

Voltage: The push behind the flowing electrons. (How bad they want to get to the positive terminal.) Or, the difference in potential between the positive and negative terminals.

Resistance: opposes the flow of electrons. It is friction is generated by the electrons moving through the material.

Current: Electrons flowing through the wire

11. Draw a schematic of an open circuit that contains a battery, a resistor and a bulb. Label each component. Would the bulb be lit?

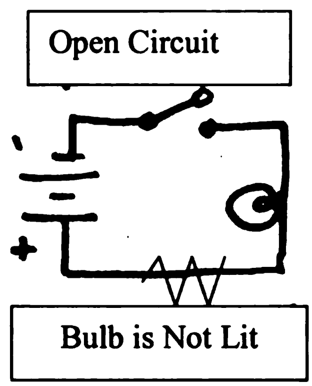


Figure 36 Open Circuit With Resistor and Bulb (teacher's drawing)

12. Draw a schematic of a closed circuit that contains a light bulb, a battery and a voltmeter.

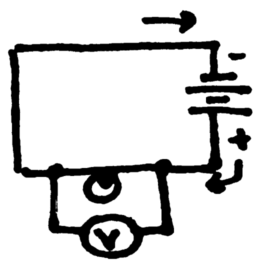


Figure 37 Closed Circuit With Bulb, Battery and Voltmeter (teacher's drawing)

13. Could an ammeter be put in the circuit above in the same place the voltmeter is shown? Explain.

    No. An ammeter needs to be connected in series, whereas the voltmeter was connected in parallel.

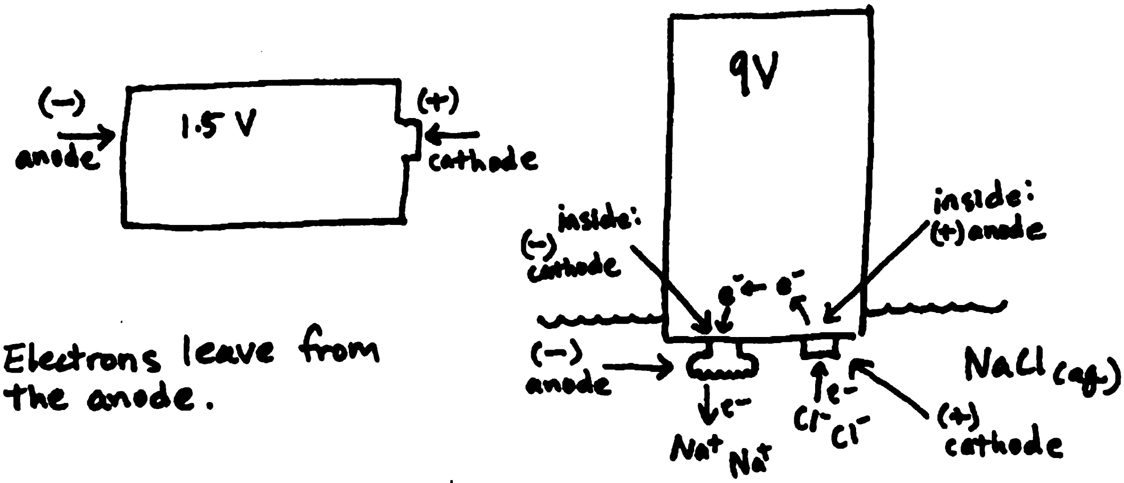
16. Name devices that transform

    a) chemical energy to electrical energy
       Battery, fuel cell

    b) mechanical energy to electrical energy
       Wind turbine, water turbine, hand-crank generator

    d) light energy to electrical energy
       Photovoltaic cell (solar cell)

17. Draw a labeled diagram of a simple battery and explain how it works.



$Na^+ + e^- \rightarrow$ **Na (reduced)** $2Cl^- \rightarrow Cl_2 + 2e^-$ **(oxidized)**

Figure 38 Batteries and How They Work (teacher's drawing)

When discharging, the electrons are produced at the anode and flow through the load toward the cathode. An electrolyte inside the battery provides the electrons.

18. If you wanted to increase the voltage output of a solar panel, would you connect the individual solar cells in series or in parallel? Explain.

You would connect it in series because their voltages would add together. (In a parallel circuit there is more than one path to take so the initial pressure is split between the available paths.)

19. What is the benefit of having Christmas tree lights wired in parallel instead of series?

There is more than one path for the electrons to follow. If one bulb burns out there are still other paths that the electrons can follow and the other bulbs will stay lit.

ELECTRICITY UNIT
ANALYSIS OF RAW DATA FROM PRETEST AND POST TEST

Scores entered into the t-tests were based on a ratio of correct responses to total responses as the questions were open-ended and students could volunteer multiple responses.

1. Name devices that transform chemical energy to electrical energy. (Benchmark P4.10B)

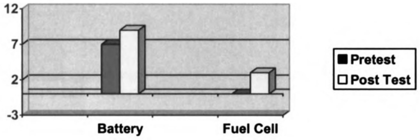


Figure 39 Correct Responses for Question 1

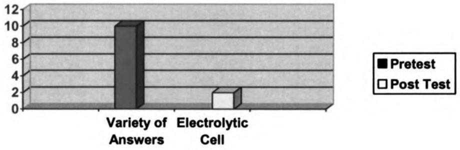


Figure 40 Incorrect Responses for Question 1

According to the t-test (probability 0.152), the increase in knowledge as measured by the scoring process was insignificant. The number of correct answers increased by 71%. The number of incorrect answers decreased by 80%. No students gave fuel cell as a response before the unit, whereas 25% of them named fuel cell at the end of the unit. Unfortunately, our work with electrolytic cells confused some students, as two of them

(17%) wrote that in as an incorrect response. Overall, students showed significant improvement in this concept after the unit.

2. Name a device that transforms light energy to electrical energy.
(Benchmark P4.10B)

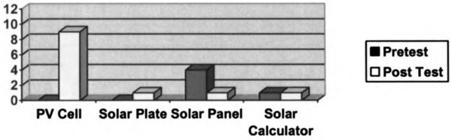


Figure 41 Correct Responses for Question 2

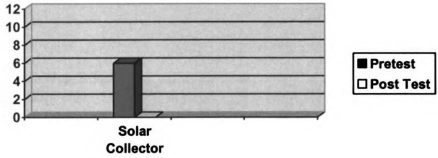


Figure 42 Incorrect Responses for Question 2

According to the t-test results the knowledge gained was significant (probability 0.008). The number of correct answers increased by 140%. The number of wrong answers was greater than the number of right answers before the unit. After the unit there were no incorrect responses given. Before the unit none of the students used the term photovoltaic cell, which is the most specific term currently in use for the device. After the unit, 75% of the responses used this terminology. Students showed significant improvement in this concept after the unit.

3. Name devices that transform mechanical energy to electrical energy. (Benchmark P4.10B)

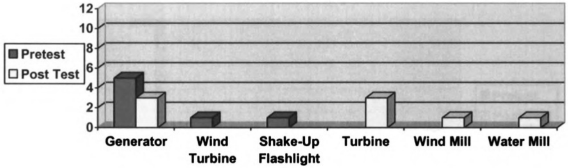


Figure 43 Correct Responses for Question 3

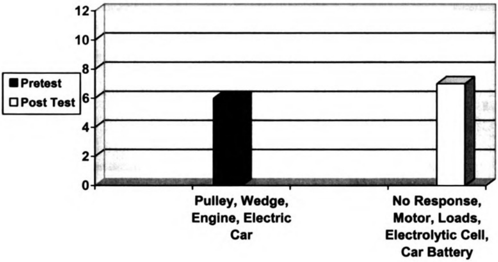


Figure 44 Incorrect Responses for Question 3

From the percentages it appears that significant progress was not evident for this concept after the unit. The increase in correct answers was only 14%, which amounts to one more student giving a correct response on the Unit 3 Test than on the pretest. And on the post test, the total number of incorrect answers had actually increased by 17% due to the open-ended nature of the question allowing for multiple answers. T-Test results also show no significant change in student knowledge (probability 0.493).

4. Draw an example of a closed circuit.
   (Benchmark P4.10C)

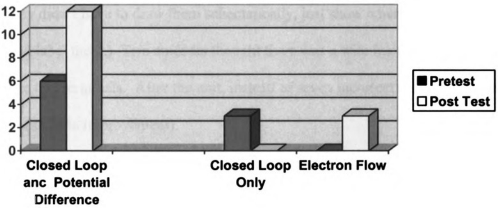


Figure 45 Correct Responses for Question 4

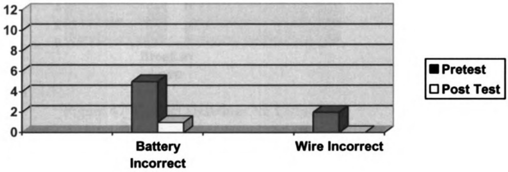


Figure 46 Incorrect Responses for Question 4

According to the t-test, the increase in knowledge as measured by the scoring was significant (probability 0.016). On the pretest, most students that drew the closed circuit correctly drew a D-cell battery with a wire going from one terminal to the other with nothing else in the drawing. On the post test students used schematic symbols and incorporated other elements into the circuit such as bulbs and voltmeters. The number of students who knew that a closed circuit consisted of a continuous loop and a potential difference increased from 6 to 12, a 100% improvement. Before the unit, none drew electron flow. After the unit, three of them included it even though it wasn't asked for.

Before the unit, five students couldn't even depict battery terminals in a correct manner. (They didn't have to draw them schematically, just show where they were on the battery and label them.) Two students thought there was a wire inside the battery connecting the two terminals. After the unit, instead of seven incorrect drawings, there was only one (an 86% improvement).

5. Draw an open circuit.
   (Benchmark P4.10C)

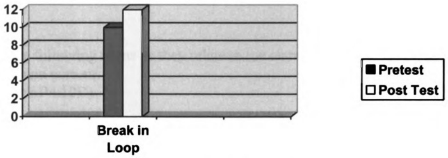


Figure 47 Correct Drawings for Question 5

Before the unit, most students (83%) already knew that an open circuit has a break in it. After the unit, 100% of the students drew the circuit correctly. According to the t-test the change in scores was not significant and could have been due to chance (probability 0.341).

6. If a light bulb was included in the circuits above, in which if either, would it be lit? (Benchmark P4.10C)

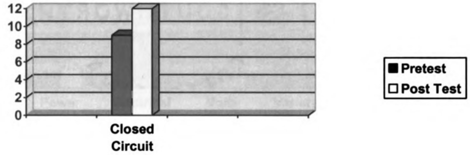


Figure 48 Correct Response for Question 6

As with the open circuit drawing, most students (82%) already knew that the bulb would light up in the closed circuit only. After the unit 100% of them gave the correct response. According to the percentages it looks as if the unit was effective at bringing the stragglers up to snuff. However, the t-test indicates that the change in scores could have been by chance (probability 0.167).

7. Explain the following terms as they relate to the circuit you drew: voltage, resistance and current.
(Benchmark P4.10D)

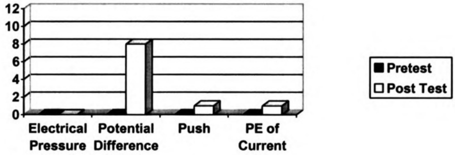


Figure 49 Correct Responses for the Voltage Part of Question 7

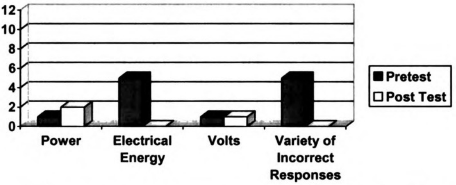


Figure 50 Incomplete and Incorrect Responses for Voltage Part of Question 7

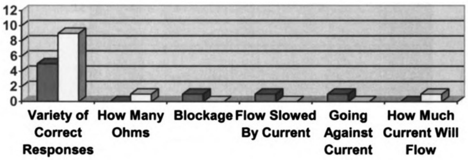


Figure 51 Correct Responses for Resistance Part of Question 7

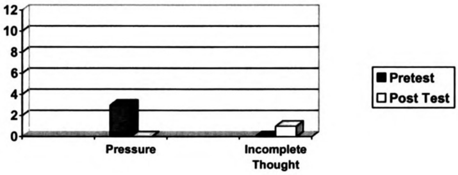


Figure 52 Incorrect Responses for Resistance Part of Question 7

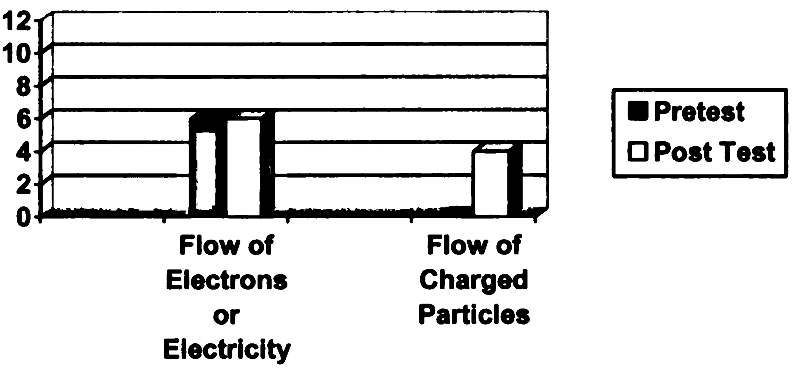


Figure 53 Correct Responses for Current Part of Question 7

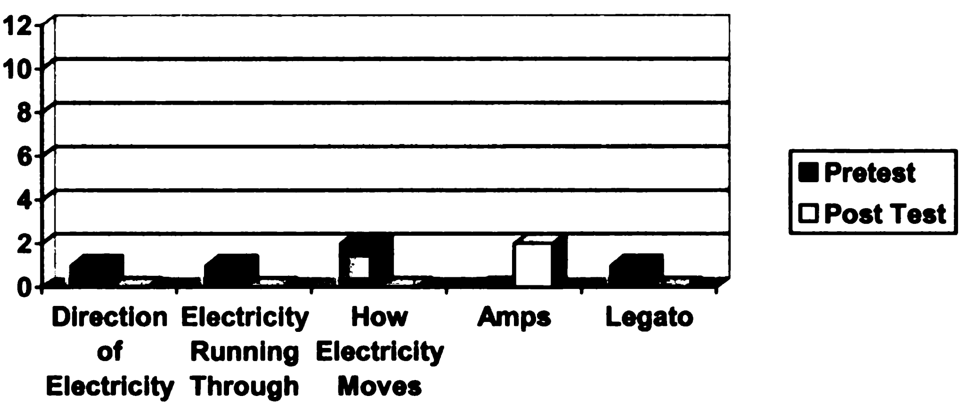


Figure 54 Incorrect Responses for Current Part of Question 7

Students showed marked improvement in their understanding of both voltage (up from 0% to 80%) and resistance (80% improvement). Their understanding of current showed no improvement. T-test results indicate that the gains in scores on voltage were significant (probability 0.000). But the gains in resistance and current were not (probabilities of 0.052 and 0.082 respectively).

8. Draw a simple battery and explain how it works.
   (Benchmarks P4.10C and P4.10.B)

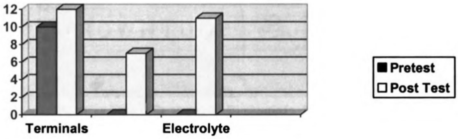


Figure 55 Correct Details on Drawing for Question 8

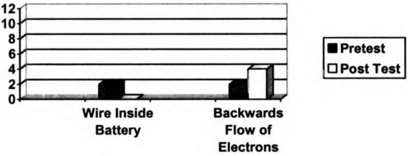


Figure 56 Incorrect Details on Drawing for Question 8

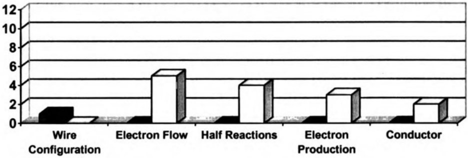


Figure 57 Correct Explanation for Question 8

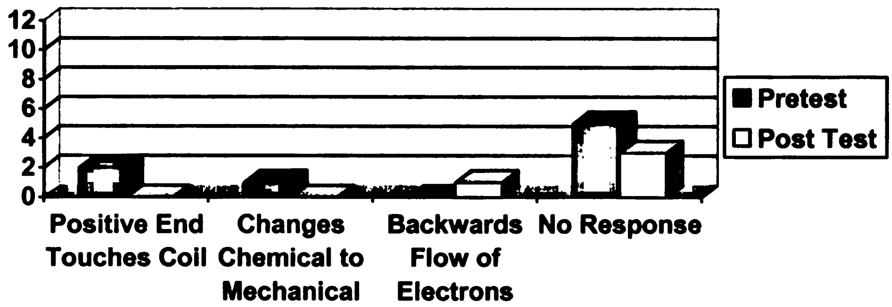


Figure 58 Incorrect Explanation for Question 8

Huge gains were seen in the task of drawing a battery and explaining how it works. The t-test confirms that gains in scores on the drawing were significant (probability 0.000). Before the unit, ten students drew and labeled positive and negative terminals, but none showed the electrolyte or direction of electron flow. After the unit all 12 of the students drew and labeled the terminals. Eleven of them showed the electrolyte and seven the direction of electron flow. After the unit students no longer drew wires inside the batteries. However, the number of students showing backwards electron flow doubled from two to four. This is probably related to teaching both electrolytic cells and batteries. That part of the unit needs to be reworked as it has also caused confusion in terminal names and charges.

Students' written explanations of how the battery works seemed to show substantial. However, t-test results showed that it could have been due to chance (probability 0.1730). Before the unit there was only one correct response and four that were partially correct. After the unit, there were 14 correct responses, a 250% improvement. Describing one aspect of how a battery works, such as saying that ions are produced, counted as one response. So one individual student's answer could count as more than one response on the data chart.

9. If you wanted to increase the output of a solar panel, would you connect the individual cells in series or parallel? Explain.
(Benchmark P4.10g)

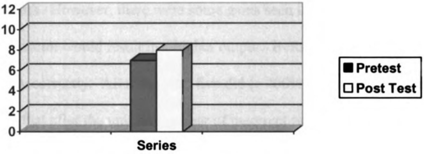


Figure 59 Correct Responses for Question 9

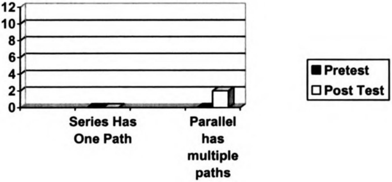


Figure 60 Correct Explanation for Question 9

Referring to a collection of photovoltaic cells as a solar panel was done on purpose. I did not want to give students the answer to question 2 by using the term photovoltaic cell in this question. The fact that I was talking of making electricity rather than heating water should have been clear due to the wording of the question.

T-test results show changes in scores to be due to chance with the probability of chance for the explanation portion of the question to be 0.291 and for the drawing portion 0.666. Gains seen by students on this topic are zero as far as being able to name whether the series or parallel circuit would be the one to give the desired results. Note that 12 students took the post test and only 11 did the Pretest. For both tests, four students had incorrect responses. The unit needs to better address the concept of voltages add together in series circuits. However, there were some gains seen in students being able to explain why a series circuit would result in a higher output. Before the unit only one student explained why correctly. After the unit, five did (a 400% increase). It is worth noting here, though, that after the unit the number of incorrect responses was almost the same as it was before the unit. Recall that a single could list multiple reasons and each reason would count as a response.

10. If the lights on your Christmas tree were wired in series, what would happen if one of them burned out?
(Benchmark P4.10g)

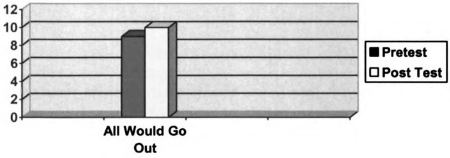


Figure 61 Correct Responses for Question 10

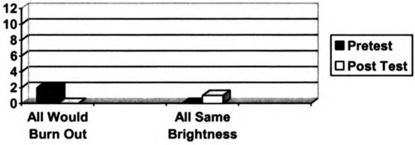


Figure 62 Incorrect Responses for Question 10

Most students already knew that all the lights would go off if they were wired in series. The gain was virtually zero since one more person took the post test than the pretest. And the t-test analysis of scores indicates the change was not significant (probability 0.557). It does seem that the unit was successful at communicating that a burned out bulb has a break in the circuit (a broken filament) as no students mentioned that term in their response after the unit. On the post test, nine of the twelve students, or 75%, gave no explanation. This was the fault of the evaluation instrument. The question as it appeared on the post test did not ask for an explanation. Therefore the post test did not supply the data necessary to tell whether the unit was successful in teaching students why the lights in a series would go out if one burned out, but would stay lit in a parallel circuit.

APPENDIX III I

Building a Photovoltaic Cell
Post-Lab Questions

To Accompany "Discussion" Handout

1. Why are solid-state solar cells so expensive?

2. What is so great about dye-sensitized solar cells?

3. Considering the anode, which was coated with nanocrystalline titanium oxide and later dyed with hibiscus,

    a) What wavelengths does undyed titanium oxide absorb?

    b) What wavelengths does it absorb after being dyed?

    c) What was the reason for using a nanocrystalline form of TiO_2?

4. The functioning of the dye-sensitized solar cell is similar to the functioning of which biological process?

5. Why do leaves look red and orange in the fall?

6. In the photovoltaic cell that we made, what is the function of the

    a) dye?

    b) titanium oxide (anode)?

    c) iodine/potassium iodide electrolyte?

    d) graphite cathode?

7. What causes the electrons to flow from the anode to the cathode through the voltmeter (or some external circuit that would power your lights)? THINK OF WHAT WE LEARNED IN THIS CHAPTER.

Building a Photovoltaic Cell
Post-Lab Questions
To Accompany "Discussion" Handout

1. Why are solid-state solar cells so expensive?
They require large, high purity silicon crystals for greatest efficiency. These crystals are very expensive, both the raw materials and the manufacture.

2. What is so great about dye-sensitized solar cells?
The two functions of light absorption and electron transfer and separate, so can be engineered for maximum efficiency separately.

3. Considering the anode, which was coated with nanocrystalline titanium oxide and later dyed with hibiscus,

   a. What wavelengths does undyed titanium oxide absorb? **Ultraviolet**

   b. What wavelengths does it absorb after being dyed? **Visible**

   c. What was the reason for using a nanocrystalline form of TiO_2?

   It provides more surface area so more light is absorbed.

4. The functioning of the dye-sensitized solar cell is similar to the functioning of which biological process?
It is similar to the way chlorophyll makes use of light in photosynthesis.

5. Why do leaves look red and orange in the fall?
Those pigments are always there, but are normally masked by the green color of chlorophyll. In the fall when the chlorophyll is inactivated you can see through it to the orange and red.

6. In the photovoltaic cell that we made, what is the function of the

   a. dye? **It absorbs visible light and electrons in the atoms of dye are promoted from the ground level to a higher energy level.**

   b. titanium oxide (anode)? **It oxidizes the dye (takes an electron away from it).**

   c. iodine/potassium iodide electrolyte? **It is a redox catalyst. The iodide anion donates electrons to the dye.**

   d. graphite cathode? **The graphite reduces I_2 to I^- by using the electons traveling to it from the anode.**

7. What causes the electrons to flow from the anode to the cathode through the voltmeter (or some external circuit that would power your lights)? THINK OF WHAT WE LEARNED IN THIS CHAPTER.

   The potential difference between the titanium oxide and the graphite causes the movement of electrons.

RAW DATA AND ANALYSIS
FROM BUILDING A PHOTOVOLTAIC CELLPOST LAB QUESTIONS

The data below was gathered for the purpose of analyzing student motivation rather than mastery of any benchmarks.

Scores Earned on Just the Assignments That Were Turned In	Number of Questions Attempted Just for the Assignments That Were Turned In
6 / 12 = 50%	11 / 12 = 92%
8.5 / 12 = 71%	11 / 12 = 92%
7.5 / 12 = 63%	12 / 12 = 100%
3 / 12 = 25%	9 / 12 = 75%
1 / 12 = 8%	4 / 12 = 33%
2.5 / 12 = 21%	7 / 12 = 58%
4 / 12 = 33%	10 / 12 = 83%
8 / 12 = 67%	12 / 12 = 100%
8 / 12 = 67%	12 / 12 = 100%
0 / 12 = 0% (late)	forgot to record this data for the late paper
10.5 / 12 = 88%	12 / 12 = 100%

Average Score: 45% **Average Percentage Attempted: 83%**

Table 21 Responses on Photovoltaic Cell Post Lab Questions

Number of Students That Handed The Assignment In	Number of Students That DID NOT Hand the Assignment In
11	2

Table 22 Number of Assignments Turned In

Answers for every question on the post lab could be found on a sheet that I gave to the students. It was the discussion section of Flinn's lab publication that comes with the kit for building photovoltaic cells. (See the implementation section for more information.) The discussion sheet contained a detailed explanation of dye-sensitized photovoltaic cells, which is the type that we made. It also contained a diagram explaining the function of various components of this type of PV cell. I asked students to copy the labeled diagram off the discussion sheet before attempting to answer the post lab questions.

All of the questions, except the very last one, could be answered by just reading the discussion carefully and looking over the diagram. The low scores (average 45%) seem to indicate very low motivation. Three students received zeros, two of them because they did not turn in the assignment, and one because he turned it in late. The average score of 45% does not include the zero scores of the two assignments that were not turned in. Of the ten students that turned the assignment in, only four of them attempted to answer all 12 questions.

Many of the questions that were answered appear to be things that just came off the top of their heads, with little thought and no reading time invested. For example, "What wavelengths does undyed titanium oxide absorb?" One response was "None". The actual answer as given in the reading was "visible light". Another question asked, "Why are solid state solar cells so expensive?" One response, "Because they transfer sunlight to electricity." The actual answer as given in the reading was "They require large, high purity silicon crystals."

There is a chance that some of the students did their best on the assignment, but are not able to read carefully or make sense of what they read.

CRITIQUE OF TECHNIQUE OF ANALYZING POST LAB QUESTIONS FOR BUILDING A PHOTOVOLTAIC CELL

Simply tabulating students' scores and numbers of questions attempted does not give insight into factors that may have contributed to the low scores. Perhaps it would have been valuable to hand out a questionnaire in class after students had received the assignment back. The questionnaire could ask them what factors they thought played a role in their low score. Possible answers could be:

I forgot to do the assignment last night, so I did it quick before class.

I didn't know we were supposed to read the handout.

I didn't draw the labeled diagram before trying to answer the questions.

I couldn't find some of the answers in the handout.

We had an away game last night.

I was watching TV while doing the assignment.

I didn't read carefully enough.

I think it would be best not to put these possible answers down for them to check off as excuses, but rather leave it open for them to write in their own response. It is so much easier to check off a printed response than to write your own, that it seems students would do that even if none of them really matched the reason they didn't do well. Of course, there is no guarantee either way that students will answer truthfully. There is also no guarantee that students know why they did not do well.

Another possible way to investigate the cause of the low scores could be to do the assignment in class rather than as homework. That way I could observe students to see whether they were actually reading the article and drawing the labeled diagram. They could raise their hand if they were having trouble interpreting a passage or finding an answer. However, I have observed that some students that do work in class do no work outside of class. This way of gathering more data may not help with the investigation of those students' reasons.

APPENDIX III J
ELECTRICITY POST SURVEY

1. What did we do in this chapter that really engaged you? Explain.

2. What did we do in this chapter that was boring? Explain.

3. What did you learn that you are likely to remember a long time or make use of in the future?

4. Why do you think the items you listed in #3 above ended up being the things you will remember or make most use of?

ELECTRICITY UNIT
RAW DATA FROM POST SURVEY

1. What did we do in this chapter that really engaged you? Explain.

Labs in General (hands-on) 4 students gave this response.

"I learned so much about what things are."
"I tend to learn better and follow directions better if I have things to look at and work with. Book working is sometimes confusing and harder to understand."
"All the hands-on labs (and pocket labs)."
"The labs mostly." (And then he went on to talk about building circuits.)
"The thing that drew my attention the most would have to be when we were doing hands-on things. It helps me the most if I can see what is going on."

Notes 1 student gave this response.

"Also a lot of the notes." (This came second after the student mentioned labs.)

Building Circuits (hands-on) 7 students gave this response.

"I always like it."
"Actually building the circuits...It was fun to have a hands-on experience with it."
"Because it was the most hands-on."
"When we made electricity flow from the battery and light the light bulbs."
"It really made me get involved because it was hands-on. It really helped me understand how circuits work."
"Building the various parallel circuits and series circuits. It was a fun way of learning and hands-on experience."
"The labs really help in understanding the concepts."

Building the Photovoltaic Cells (hands-on, alternative energy) 2 students gave this response.

"Even if they didn't work." (They did work! I'm not sure what she meant.)
"The labs truly helped in understanding the concepts."

Drawings 1 student gave this response.

"The drawings helped me understand the concepts too."

Math Equations 1 student gave this response

"Figuring out what makes up the power or how you get resistance. Learning about volts, ohms, watts, amps."

Fuel Cells (alternative energy) 1 student gave this response.

"About how fuel cells can't be the next greatest thing in helping to reduce emissions from cars."

Car Batteries 1 student gave this response.

"The whole part of learning about how car batteries work."

2. What did we do in this chapter that was boring? Explain.

Nothing 2 students gave this response.

"Because it all related to real life."
"I feel pretty much everything was informative, not boring."

Reading out of the Book 1 student gave this response.

"I'd rather take notes or do a lab, because having other people read doesn't do much for my understanding. I'd rather read it at home myself."

Math 2 students gave this response.

"The math, I guess. But its hard to make math exciting. I was just kind of confused."
"Problems out of the book. (I like it when the teacher does practice problems for us.)"

Fuel Cells (alternative energy) 1 student gave this response.

"Learning about fuel cells was not only boring, but hard to understand. Therefore I didn't take the time to understand."

Notes 3 students gave this response.

"Probably taking the same notes over and over again. It helped in the long run, but it was still boring."
"I don't mind notes, but there was a lot. I used up half of my notebook."
"Some seemed repetitious and long."

Penny, Nickel, Electrolyte Lab (hands-on) 2 students gave this response. They are referring to the Voltaic Pile Lab.

"Because it wasn't very involved. Also the purpose wasn't appealing to me."

"The salt pennies."

Middle School Packets 1 student gave this response.

"Because they were so easy. Even though those packets were so boring, I think it refreshed and helped me understand what was going on."

Drawings 1 student gave this response.

"Some of the drawings were a little confusing because there's just so much going on, and not enough room on the paper."

Hybrid Cars (alternative energy) 1 person gave this response.

"I did not think the stuff about all the plebic hybrid car." (incomplete thought?)

Photovoltaic Lab (hands-on and alternative energy) 1 person gave this response.

There were no comments.

Worksheets 1 person gave this response.

"Because I like being active and building stuff and seeing how things are put together."

3. What did you learn that you are likely to remember a long time or make use of in the future?

How a Battery Works 3 students gave this response.

There were no comments.

How a Car Battery Works 3 students gave this response.

"And how to draw one."
"The car battery demo, I could probably use again."
"Very helpful in the future."

How to Build a Photovoltaic Cell (alternative energy and hands-on) 1 student gave this response.

"Because it was interesting and had a lot of precise steps."

Fuel Cell (alternative energy) 5 students gave this response.

"Stuff about it."

"The possibility of getting a fuel cell since it is better for the environment."
"Very helpful in the future."

Circuits (some referred to hands-on) 5 students gave this response.

"How they work."
"Circuit building."
"Schematic symbols and how to use them to make a drawing."
"How a series and parallel circuit works, and which one to use in a certain situation."
"Series and parallel circuits always have a role in people's lives."

Energy Efficient Cars (alternative energy) 2 students gave this response.

"About energy efficient cars."
"I'll probably get a hybrid when I'm older if they haven't come up with something better by the time I can afford my own car."

Alternative Energy Sources (alternative energy) 1 student gave this response.

There were no comments.

Math Equations 1 student gave this response.

"$P = VI$, $V = IR$, $E = Pt$"

Resistance 2 students gave this response.

"Longer wire makes more resistance than a short wire. Bigger wire is less resistance than skinny wire."
"All the information about resistance was useful."

Voltage 1 student gave this response.

"How it is really important and can change."

Electricity 1 student gave this response.

"All the information on electricity I learned."

4. Why do you think the items you listed in #3 above ended up being the things you will remember most or make most use of?

Interesting 3 students gave this response.

"The car battery is just interesting to me."

"They were things that most interested me (circuit building, alternative energy sources, fuel cells, hybrid cars) and something I find interesting is easier to remember than something boring."
"Because it interested me." (fuel cell and battery)

<u>Environmental Technology</u> (alternative energy) 1 student gave this response.

"The fuel cell is going to be the next greatest thing to stop global climate change and reduce emissions."

<u>Physical</u> (hands-on) 1 student gave this response.

"Because the were physical. I could see and touch them and observe how things worked." (photovoltaic cell building, how a car battery works and how to draw one)

<u>Useful</u> 3 students gave this response.

"I can use the info I learned about batteries and electricity when I leave the classroom."
"Because I don't need to know exactly how a fuel cell works." (She did not list fuel cell in #3.) "Because I want to be a teacher so just knowing the basics and remembering them will benefit me the most."
"They (schematic symbols) can be useful for electricians and engineers."

<u>Everyday Life</u> 3 students gave this response.

"Because they are the things that come up in everyday life, not just science."
"I know I can use them (resistance and voltage) in everyday life as I grow older."
"Because I will always use batteries. They are important things in my life, we use them practically everywhere."

<u>Simple</u> 2 students gave this response.

"Because it (schematic symbols) was a simple concept to understand."
"Equations like this (V=IR, P=VI, E=Pt) are simple and easy."

<u>Read in Our Books</u> 1 student gave this response.

"I think I will remember resistance and voltage because we read in our books."

ELECTRICITY UNIT
ANALYSIS OF DATA FROM THE POST SURVEY

1. What did we do in this chapter that really engaged you?

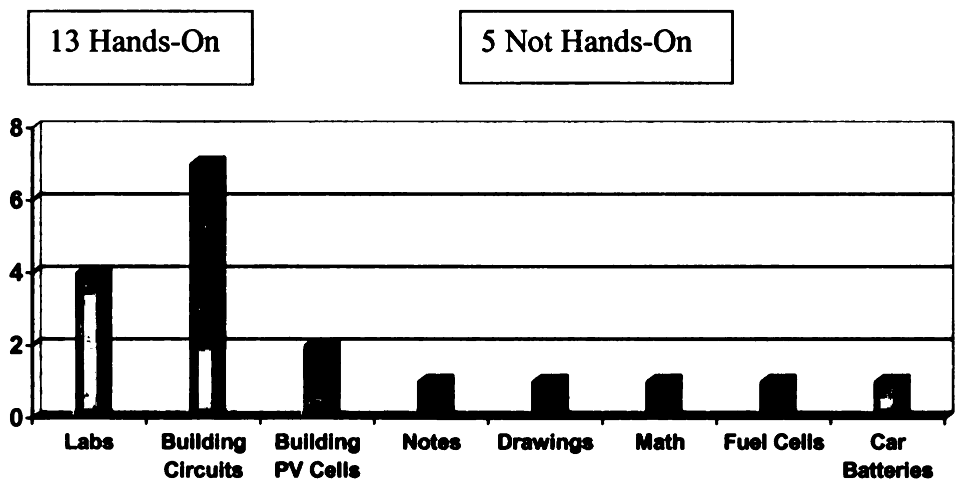


Figure 63 Responses Classified by Hands-On

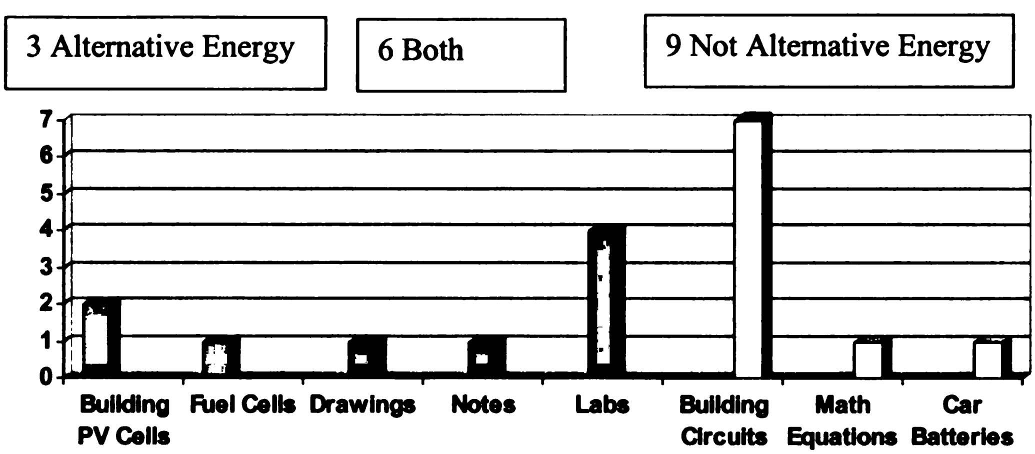


Figure 64 Responses Classified by Alternative Energy

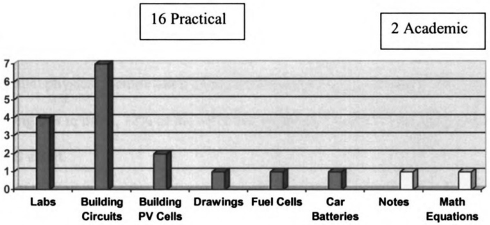


Figure 65 Practical Versus Academic Responses

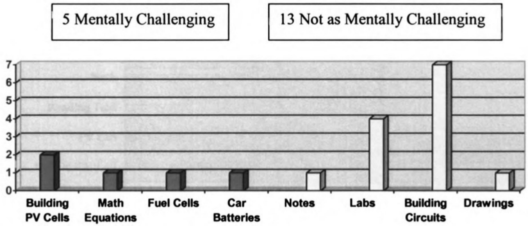


Figure 66 Responses Classified According to Mental Challenge

Thirteen responses mentioned hands-on activities. Five mentioned things that were not hands-on. So 72% of the things students listed as being really engaging were hands-on. Students listed fewer alternative energy activities as enjoyable. Disregarding the activities that partly dealt with alternative energy and partly dealt with other topics, only 25% of the activities listed as really engaging dealt predominantly with alternative energy.

An overwhelming 89% of the 18 responses had to do with practical topics rather than more academic pursuits. Note that when students list "labs" I am assuming they mean the actual physical manipulation of equipment according to the comments they included. Keeping this in mind, 72% of the activities mentioned as really engaging required little mental effort.

2. What did we do in this chapter that was really boring?

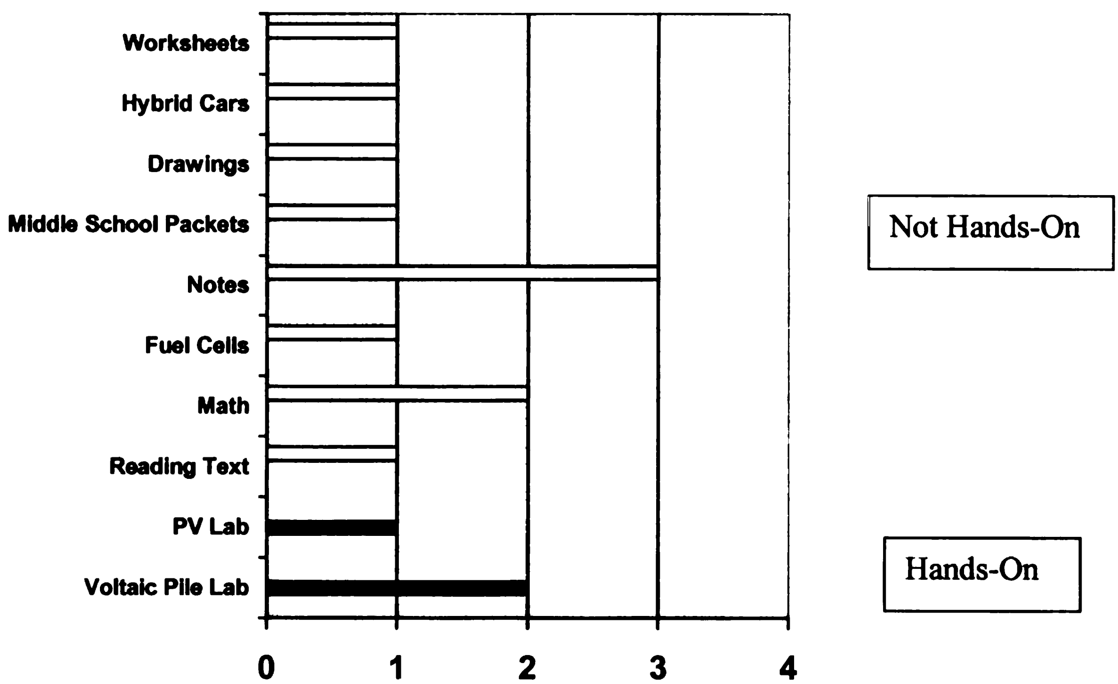


Figure 67 Responses Classified by Hands-On

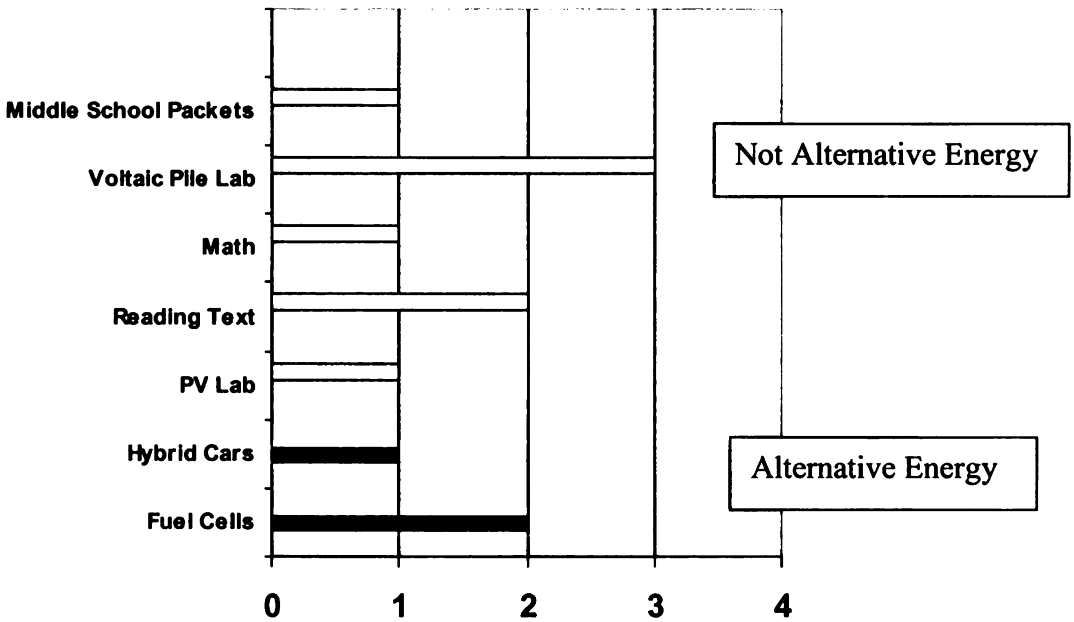


Figure 68 Responses Classified by Alternative Energy

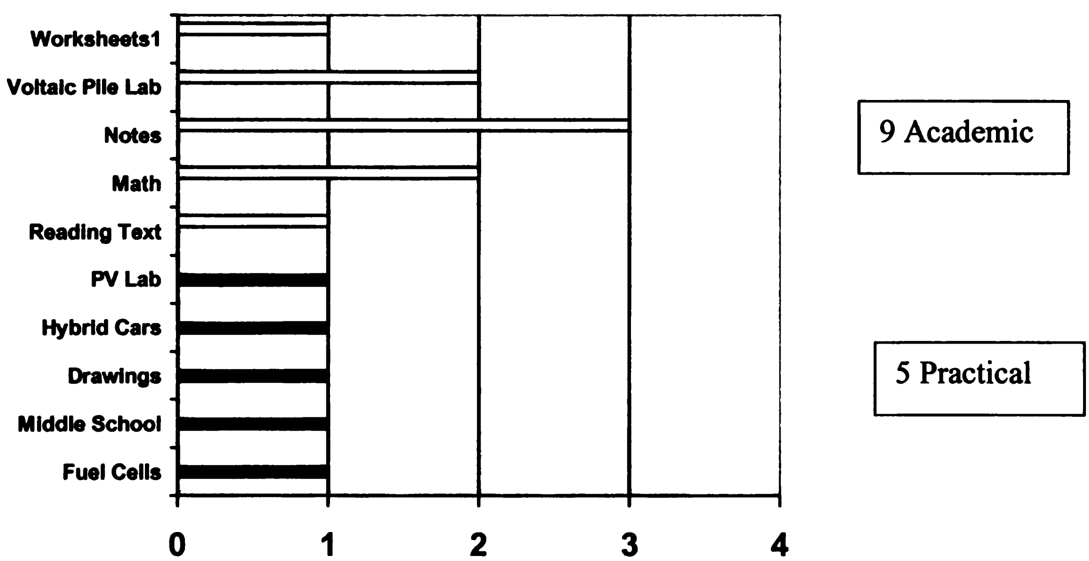


Figure 69 Practical Versus Academic Responses

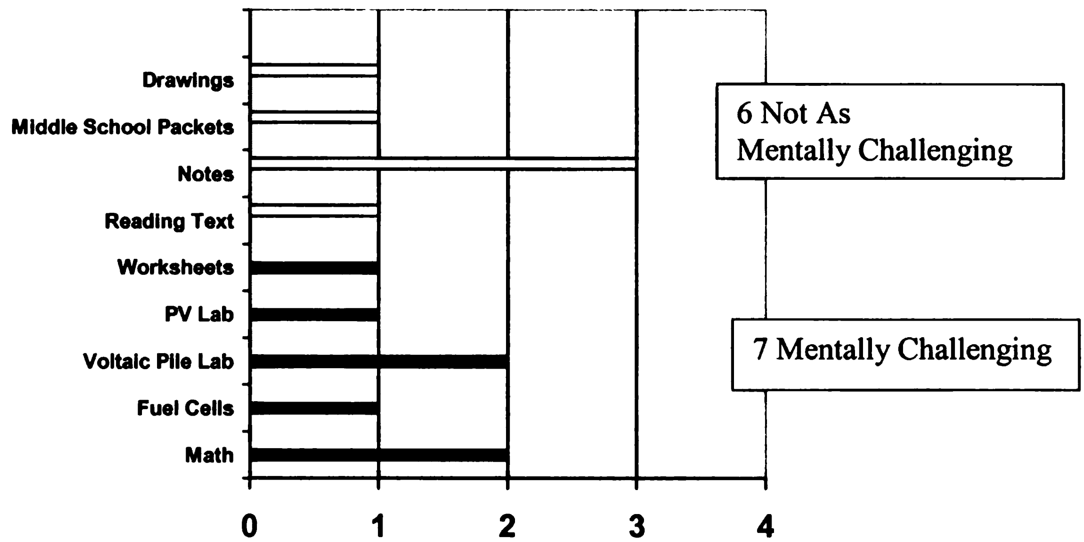


Figure 70 Responses Classified According to Mental Challenge

Only 21% of the items students listed as boring were hands-on activities. This is similar to the data for question number one. In the graph that grouped activities according to alternative energy, the activities that were partly alternative energy and partly not were not included. These included notes, drawings and worksheets. Only 33% of the items mentioned as boring had to do with alternative energy.

Deciding whether an activity was more practical or academic was pretty subjective. However, with the way the activities are categorized above, 64% of the items listed as boring were academic and 36% were practical.

They hybrid car activities were not included in the graph whose criteria is mental challenge. This was because watching the slides did not take much mental effort, but trying to understand the half reactions did. The data does not show a noteworthy difference between whether the activity required substantial mental effort. 54% of the activities listed as boring did and 46% did not.

3. What did you learn that you are likely to remember a long time?

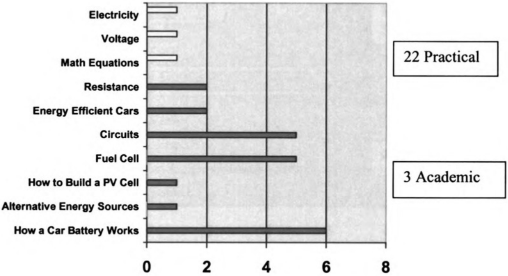


Figure 71 Practical Versus Academic Responses

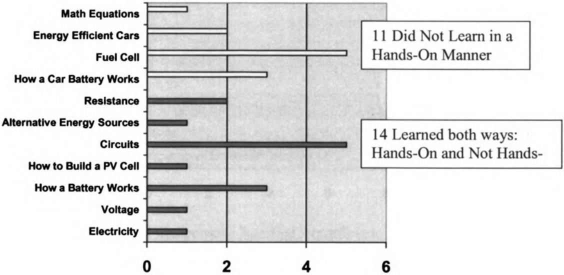


Figure 72 Responses Classified According to Hands-On

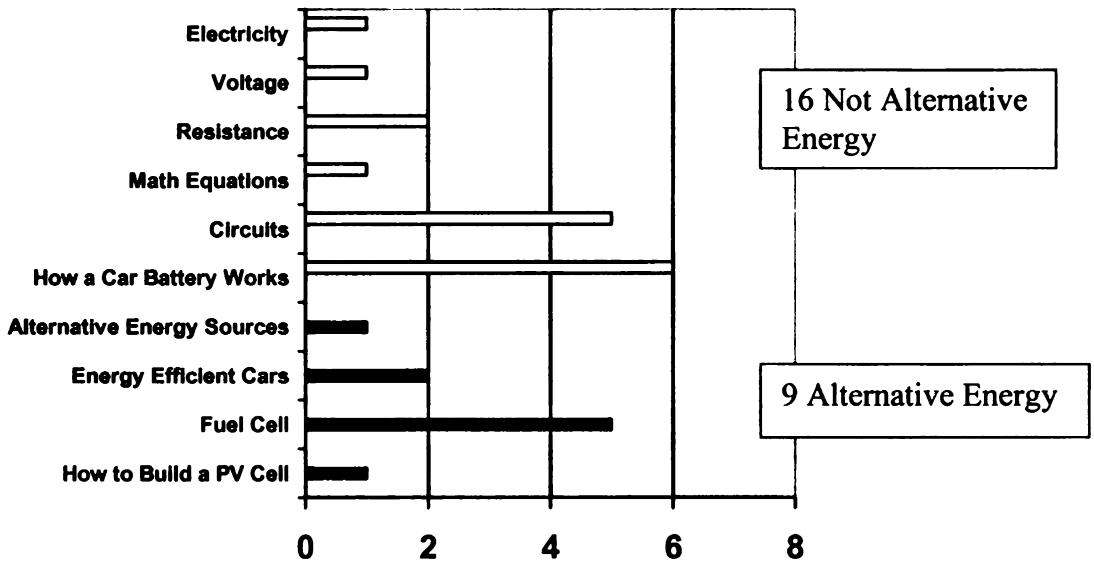


Figure 73 Responses Classified According to Alternative Energy

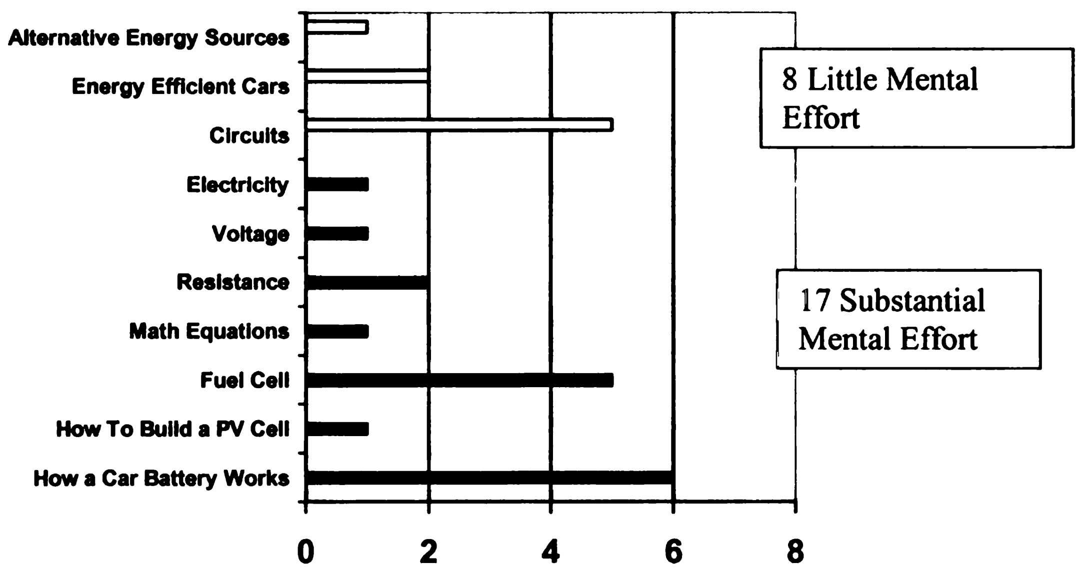


Figure 74 Responses Classified According to Mental Effort

Responses for this question definitely lean toward the practical. Almost all of the responses have to do with how things work. (See the students comments in the raw data section.) 88% of the things students felt they would remember a long time had to do with practical things.

There were really no topics that were learned in a hands-on manner only, except for the scientific research skills and experimental design skills. For those the students learned by doing, got constant feedback from myself and from the equipment and data. It seems that even though the students were very engaged in the research and experimental design, it did not occur to them that it was a topic in its own right. None of them mentioned it as a response on the post survey, although a few did in the thermodynamics post survey. When students were engaging in it, it was in the context of the current topic such as batteries or circuits.

Because all of the rest of the topics were learned either as a combination of notes, drawings, videos, demonstrations and math problems, or as hands-on with notes, drawings, videos, demonstrations and math problems, it was not possible for any of their other responses to belong to a "learned in a hands-on way only" category.

For the things students thought they would remember a long time, 56% were learned in both ways and 44% were learned without a hands-on component. This is not a huge difference, but the 12% they differ by is worth noting. The question of whether students remember things longer, or are better able to make use of knowledge better, if it was learned in a hands-on manner would be a good question for future research.

Only 36% of the things students thought they would remember a long time had to do with alternative energy. But a clear majority of the responses dealt with topics that required substantial mental effort to learn (68%). Only 32% did not. This agrees with some earlier research done that suggests people remember things longer if they had to put a large amount of mental effort into learning them.

4. Why do you think the items you listed in #3 above ended up being the things you will remember most or make the most use of?

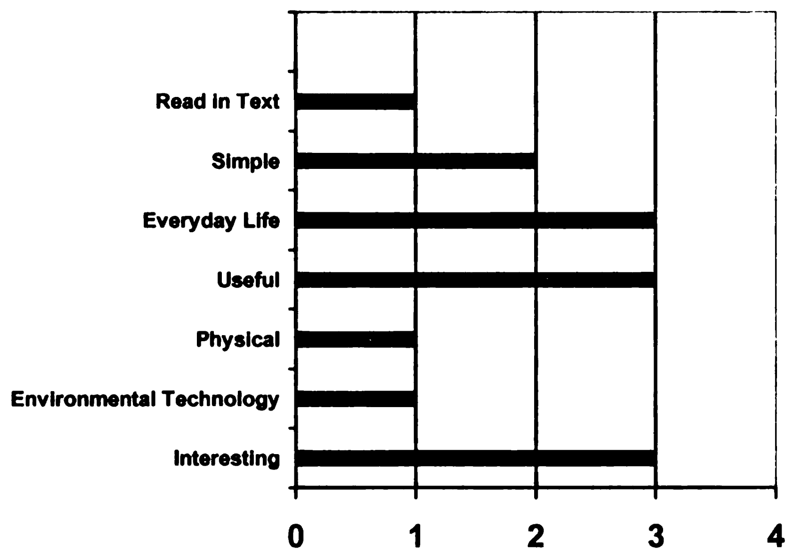


Figure 75 Explanations of Choices for Question 3

The three categories that received the most responses are things the student finds interesting, things that the student perceives as useful and things that relate to the student's daily life. These responses agree with other recent educational research.

Being a teacher I am aware of the sorts of things that research says motivate students. I chose the topic of alternative energy to teach the physics benchmarks because I thought students would find it fascinating. It is also a very practical application of thermodynamics, optics and electricity. That puts it in the useful category. Since alternative energy is in the news every day, and since many students drive and so are experiencing the high price of gasoline, it seemed like it would relate to their everyday life.

However, students did not show as much interest in the topic as I had hoped. Most are unaware of major daily news stories. And from our class discussions, it was pretty clear that although they drive and so are connected to the larger world in that context, they are still young enough that they do not have direct contact with other aspects of alternative energy. At least they don't see themselves as having direct contact. Their parents pay the utility bills, pay taxes to support a war to protect our oil supply, and make the decisions about the family's energy options. The students seem uninvolved and almost oblivious to the outside world. They do not seem to relate learning about alternative energy to protecting our jobs from going out of state or overseas. And only a few of them seem to relate it to protecting our environment.

Having come to the conclusion that the topic of alternative energy is not related closely enough to these students current everyday life, the question is what topics are? What topics could a majority of the class get excited about and motivated by? And could these topics be used to teach the benchmarks effectively?

ELECTRICITY UNIT
CRITIQUE OF DATA GATHERED IN POST SURVEY AND CRITIQUE OF THE METHOD USED TO ANALYZE IT

It is questionable whether students can accurately predict which things they will remember a long time. Their responses in that section are probably more indicative of which topics they feel are most useful or were easy for them to learn. The overall trends that seem most obvious are described below.

The students found the hands-on activities the most engaging, with building circuits the most popular of all. 89% of the responses had to do with practical topics (applied science) rather than academics (pure science). Topics listed as most engaging also favored ones that required relatively little mental effort by a ratio of 13 to 5. According to the students' data, there seems to be a negative correlation between alternative energy and the degree to which the activity engaged students.

Activities the students classified as boring were 3-1/2 times more likely to be ones where the students were not manipulating equipment, such as taking notes and doing math problems or worksheets. There were only half as many alternative energy activities listed as boring as those that were not directly related to alternative energy. Academic activities were classified as boring more often than practical topics by a ratio of 9 to 5. the amount of mental effort required played little role.

The things students are most likely to remember, according to the students, have to do with practical knowledge that required substantial effort to acquire. Topics that were learned in both a hands-on and traditional manner were slightly favored as being more likely to be remembered by a ratio of 14 to 11. Students were 1.8 more times likely to name a topic that did not have to do with alternative energy as being a topic they would remember for a long time.

According to the students' data, whether a topic is interesting, useful or related to their everyday life plays an important role in how long it will be remembered or whether it will be put to use. As mentioned earlier, the accuracy of students' predictions here is questionable.

Besides the uncertainty of students' predictions, this method of inquiry has a second drawback. Some students may write down what they think the teacher wants to hear. As an example, when asked what in this chapter students found boring, two students responded, "Nothing". That is not too likely. It was a long unit with lots and lots of different types of activities. I'm sure every student would find at least one of them boring.

Having students leave their names off the survey might help the problem of not answering truthfully. But if they don't include their name it would be difficult to award points to them for doing it. And with this group of students, if there were no points involved few would bother filling it out. And furthermore, students probably realize that the teacher probably recognizes their handwriting.

APPENDIX III K
ELECTRICITY: STUDENTS ENGAGEMENT REPORTS

SAMPLE OF STUDENTS' ENGAGEMENT DATA REPORT

Each class period, at their assigned time, each student would look around the room to see how many of his fellow students seemed to be engaged. He included himself in the data. On a piece of paper the student would record the date, time, number of students that seem to be engaged, number that do not seem to be engaged and the activity the students were supposed to be participating in. This was done to help me collect data for this thesis. Student engagement was used as a measure of motivation.

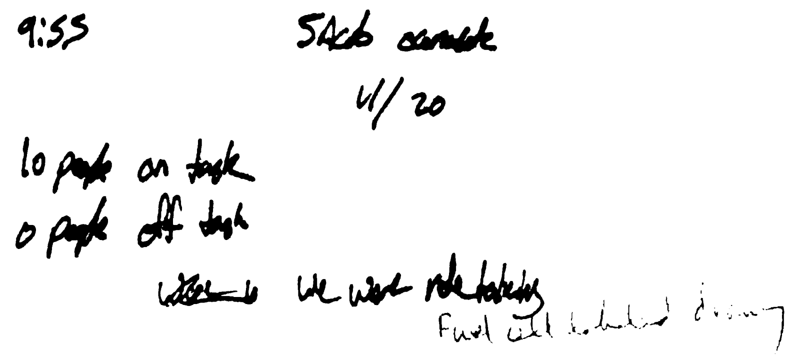


Figure 76 Engagement Report (student work)

I added the phrase "Fuel cell labeled drawing" after class so that later I would know exactly what we were doing as the student just described the activity as note taking.

ELECTRICITY UNIT
RAW COMPILED DATA ON STUDENT ENGAGEMENT

Students gathered engagement data every day during the unit. However, on days that the students were totally immersed, some forgot to record their observations. This is a compilation of the data that was collected.

Date	Activity	Students On Task	Students Off Task	Percentage On Task
11/16	Hybrid Battery Notes	12	0	100%
11/19	Slide Show on Hybrid Vehicles	10	2	83%
11/20	Labeled Drawing of a Fuel Cell	20	0	100%
11/23	Notes and Drawings on How PV Cells Work	50	5	91%
11/23	Teacher Reading Aloud on Fuel Cells	16	6	73%
11/23	Homework Quiz on PV Cells	11	0	100%
11/24	Copying Extra Credit Rubric on Fuel Cell, Hybrid Car Battery	19	3	86%
11/27	Performing Lab: Making Photovoltaic Cells	70	1	99%
11/28	Performing Lab: Making Photovoltaic Cells	77	6	91%
12/3	Labeled Drawing of PV Cell on Study Guide	12	0	100%

Table 23 Alternative Energy Activities

Date	Activity	Students On Task	Students Off Task	Percentage On Task
10/29	Working on Homework	11	0	100%
10/29	Scoring and Turning in Notebooks	22	0	100%
10/30	Going Over Homework	13	4	76%
10/30	Filling in Vocabulary on Study Guide	17	0	100%
10/31	Filling in Electricity Packets	50	0	100%
11/1	Building Circuits	76	7	92%
11/1	Going over the Test	67	15	82%
11/5	Silent Reading on Electric Potential	8	4	67%
11/5	Notes on Electric Potential	51	7	88%

Table 24 Activities Not Directly Addressing Alternative Energy

11/5	Vander Graff Demonstration	12	0	100%
11/5	Filling in Study Guide	12	0	100%
11/5	Video on Voltage is Pressure	20	4	83%
11/7	List Ways You Can Make Electricity	22	0	100%
11/7	Electrolytic Cells	81	2	98%
11/7	Performing Electrolysis Lab	12	0	100%
11/8	Notes on Resistance	24	0	100%
11/8	Going Over Electrolysis Lab	40	7	85%
11/8	Reading Aloud on Electric Power	24	0	100%
11/9	Going Over Homework	56	4	93%
11/9	Notes on Resistance	47	0	100%
11/9	Filling in Electricity Packet	12	0	100%
11/12	Notes on Using Meters	46	2	96%
11/12	Filling in Terms on the Study Guide	10	2	83%
11/12	Text Book Lab on Building Circuits	24	0	100%
11/15	Electricity Quiz	47	0	100%
11/15	Going Over the Homework	12	0	100%
11/16	Car Battery Demo	12	0	100%
11/16	Labeled Drawing of Lead/Acid Car Battery	70	2	97%
11/16	Question Sheet on Car Battery Demo	12	0	100%
11/15	Nikola Tesla Video	51	12	81%
11/19	Filling in Vocabulary on Study Guide	36	0	100%
11/19	Performing Voltaic Pile Lab	95	1	99%
11/20	Going Over Voltaic Pile Lab	28	2	93%
11/20	Notes on Electrolysis and Discharging of a Battery	38	1	97%
11/28	Organizing Notebook of Daily Work	12	0	100%
11/29	Math Problems Out of Text Book	71	7	91%
11/29	Reading Aloud on Power and Energy	11	0	100%
11/29	Video on Electric Rate	7	4	64%
11/29	Reading Aloud on Transmitting Power	11	0	100%
11/29	Notes on Transmitting Power	11	0	100%
11/30	Sample Problem Calculating Cost of Electricity	54	6	90%
11/30	Checking Homework Answers	21	1	95%
11/30	Organizing Notebook	35	0	100%
12/3	Filling in Text Book Version of Study Guide	102	4	96%
12/3	Class Discussion of Global Warming (Spontaneous)	8	4	67%

Table 24 Continued

Summarizing the raw engagement data for just the electricity unit in table 25 below allows for an analysis of both thermodynamics and electricity together in the next section.

Activity Category	Students on Task	Students off Task	Percent of Students on Task
Alternative Energy	297	23	93%
Other Than Alternative Energy	1501	72	95%

Table 25 Summary by Category for the Electricity Unit

ANALYSIS OF DATA OF STUDENT ENGAGEMENT FROM ELECTRICITY AND THERMODYNAMCIS AND OPTICS

Activities Involving Alternative Energy	Activities That Have Portions Involving Alternative Energy	Activities Not Involving Alternative Energy
Off Task: 7%	Off Task: 10%	Off Task: 6%
On Task: 93%	On Task: 90%	On Task: 94%

Table 26 Electricity and Thermodynamics Data Analyzed According To Alternative Energy

Activities That Have Portions Involving Alternative Energy	Activities Involving Alternative Energy	Activities Not Involving Alternative Energy
Off Task: 12.5%	Off Task: 7%	Off Task: 6%
On Task: 87.5%	On Task: 93%	On Task: 94%

Table 27 Alternative Energy Activities With Tests, Quizzes, Surveys and Notebooks Removed

Hands-On Activities	Activities That Are Partially Hands-On	Activities That Are Not Hands-On
Off Task: 4%	Off Task: 0%	Off Task: 8%
On Task: 96%	On Task: 100%	On Task: 92%

Table 28 Electricity and Thermodynamics Data Analyzed According to Whether it is Hands-On

Hands-On Activities	Activities That Are Partially Hands-On	Activities That Are Not Hands-On
Off Task: 4%	Off Task: 0%	Off Task: 8%
On Task: 96%	On Task: 100%	On Task: 92%

Table 29 Hands-On Activities With Tests, Quizzes, Surveys and Notebooks Removed

Two things stand out clearly in the data. From the students' perspectives, on average over 90% of them are on task for all categories with one exception. The exception is for the category of activities that partially involve alternative energy when assessments have been removed from the data. Of particular note: the percentage of students off-task is cut in half when the activity is hands-on rather than passive. Even more noteworthy is the data for activities that are partially hands-on. One hundred percent of students were judged as on-task during those activities. Perhaps that sort of activity is a good fit for these high school students.

There seems to be little difference between percentages of on-task and off-task students when analyzing according to whether the task involved alternative energy. Although the category of activities that were partially alternative energy gives puzzling data.

The amount of data collected for the various activities shows how lopsided the curriculum is even when the instructor makes a conscious effort to include alternative energy and to emphasize hands-on activities. A majority of the data was collected during activities that were not hands-on and that did not directly involve alternative energy. Going by the data collected, it appears that 80% of the time was spent on activities that did not involve alternative energy and only 19% of the time was spent on hands-on activities.

CRITIQUE OF TECHNIQUE OF USING STUDENT ENGAGEMENT DATA COLLECTED BY THE STUDENTS

By this unit there were still a couple of students that often neglected to write down the activity on their engagement data report, so their data was useless. The overall reliability of the data is questionable as there are multiple times when a student's data does not match up with the number of students that were in class that day. For example, on a day when eleven students were present, a student listed eight as being on task and four as off-task.

From what I observed, a large portion of the time students didn't look around the room and truly try to scrutinize whether or not classmates were on task. I think they just wrote down numbers that seemed reasonable to them. Specific examples that brought me to this conclusion: Data collected day after day under the category "going over the homework", showed 90 students on task and only 9 off task. There were 12 students in the class by this unit. Every day during the time of day that I go over the homework, three or four students ask me to work out certain problems on the board. Most of the others begin socializing so loudly that we often have to stop and wait for them to quiet down before continuing. So I have a hard time swallowing the 90 to 9 ratio on the data.

The case is similar concerning data collected for the activity of filling in electricity packets as a group. These packets are meant for middle school and I use them to introduce topics in electricity as many of them have not had electricity since 7th grade. I read a sentence and the students take turns saying what goes in the blank. We go around the room in order as far as who is supposed to answer the next question. We do it at a real fast pace so that it feels kind of like a game and so that they have to stay focused to be able to fill in the answers and give their own answer when it is their turn.

The student engagement data shows that over the course of the different days that we did these packets, 83 students were on task and only 2 were off task. This does not mesh with what really happened. Each time we did this activity there would be a couple of students that would not know what question we were on every time that it was their turn. Students collecting data should have had a ratio of approximately 10 students on task to 2 students off task, so 10:2 rather than 83:2.

If instructors are going to use students to collect data, it seems they need to put the students through some training first and also a test of accuracy. Only students who prove that they take accurate data should be allowed to collect data. Otherwise, the reliability of the whole data set is in question, as it is here in this thesis.

APPENDIX III L
STUDENT GRADES AND ATTENDANCE FOR THE ELECTRICITY UNIT

This data was collected and analyzed as a measure of student motivation rather than a measure of mastery on content.

Prior Knowledge Survey October 29

Graded on completion only.
Total possible points: 10

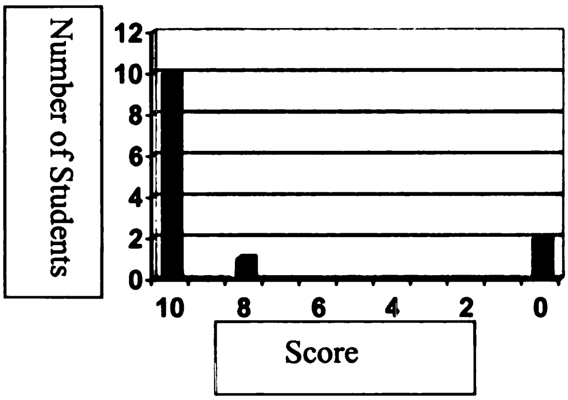


Figure 77 Scores on the Prior Knowledge Survey

The two students that received zeros were absent and their absences were unexcused.
Average score (excluding the zeros): 9.8 (98%)
Average score (including the zeros): 8.3 (83%)

Homework Quiz October 30

Graded on accuracy.
Total possible points: 5

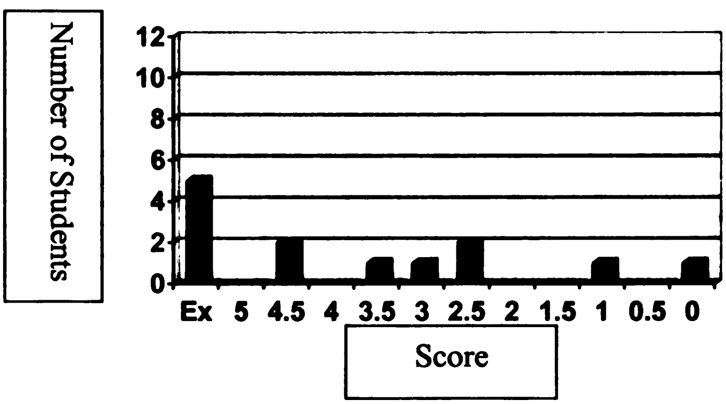


Figure 78 Scores on the Homework Quiz

The five students that were excused from the quiz had excused absences that day.
The student who received a zero was absent and unexcused.

Average score (excluding the zero): 3.1 (62%)
Average score (including the zero): 2.7 (54%)

<u>Electricity Quiz</u> November 13

Graded on accuracy.
Total possible points: 25

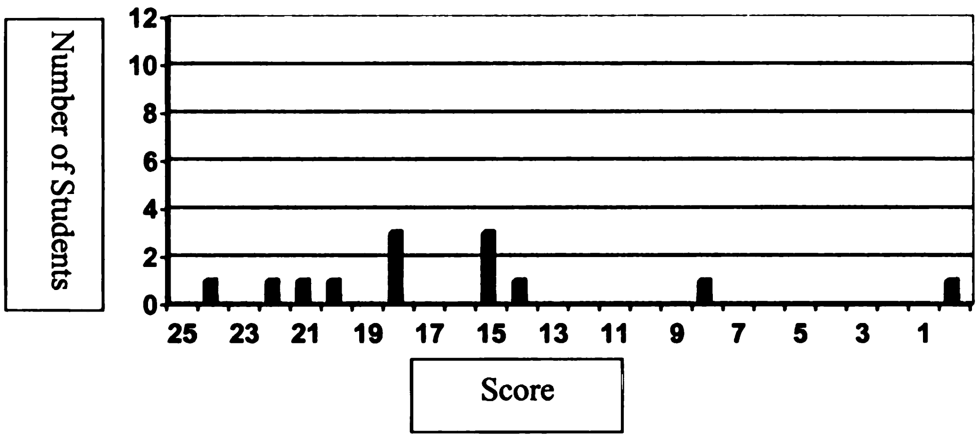


Figure 79 Scores on the Electricity Quiz

The student who received a zero was absent and unexcused.
Average score (excluding the zero): 17.4 (70%)
Average score (including the zero): 16.1 (64%)

<u>Photovoltaic Post Lab Questions</u> November 29

Graded on accuracy
Total Possible Points: 12

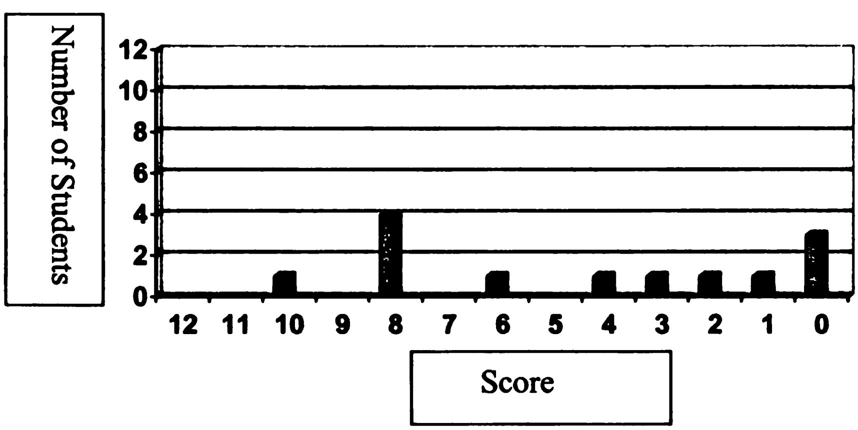


Figure 80 Scores on the Photovoltaic Post Lab Questions

Of the three students that received a zero, one handed it in late, two did not hand it in at all and one of them had an unexcused absence on the day it was due.
Average score (excluding the zeros): 5.9 (49%)
Average score (including the zeros): 4.5 (38%)

<u>Electricity Test</u> December 4

Graded on accuracy
Total possible points: 100

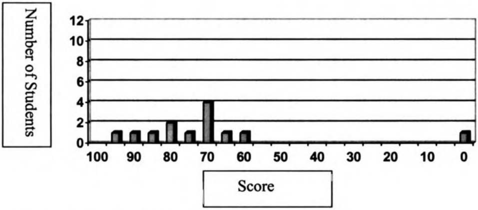


Figure 81 Scores on the Electricity Unit Test

The person that earned a grade of zero was absent and unexcused.
Average score (excluding the zero): 77 (77%)
Average score (including the zero): 71 (71%)

<u>Notebook of Daily Work For Whole Electricity Unit</u> December 4

Graded on completion only.
Total possible points: 81.5

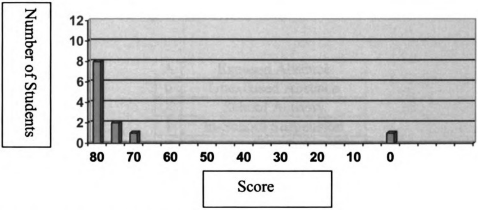


Figure 82 Scores on the Notebook of Daily Work

The student receiving a zero was absent and the absence was unexcused.
Average score (excluding the zero): 79 (97%)
Average score (including the zero): 73 (90%)

Daily Attendance

Date	1	2	3	4	5	6	7	8	9	10	11	12	13
Monday, Oct. 29	u	u											
Tuesday, Oct. 30	X	X	X	X	X								
Wednesday, Oct. 31	X	X	I										
Thursday, Nov. 1	S												
Monday, Nov. 5	S												
Tuesday, Nov. 6													
Wednesday, Nov. 7	u												
Thursday, Nov. 8	u												
Friday, Nov. 9	u												
Monday, Nov.12	u												
Tuesday, Nov. 13	u												
Wednesday, Nov. 14	u												
Thursday, Nov. 15	u	A											
Friday, Nov. 16	u												
Monday, Nov. 19	u												
Tuesday, Nov. 20	u	A	A										
Monday, Nov. 26	u	A											
Tuesday, Nov. 27	u												
Wednesday, Nov. 28	u												
Thursday, Nov. 29	u	A											
Friday, Nov. 30	u												
Monday, Dec. 3	u												
Tuesday, Dec. 4	u												
Wednesday, Dec. 5	u												

Table 30 Attendance During the Electricity Unit

A	Excused Absence
u	Unexcused Absence
X	School Activity
I	In-School Suspension
S	Out-of-School Suspension

Table 31 Key to Attendance Symbols

Student	Number of Absences	Unit Test Grade (%)
1	2	91
2	1	66.5
3	2	94
4	2	70.5
5	2	77
6	0	89
7	22	0
8	1	70
9	0	60
10	0	80
11	2	81
12	1	70
13	0	71

Table 32 Attendance by Student

ELECTRICITY UNIT
ANECDOTAL COMMENTARY ON GRADES AND ATTENDANCE

Attendance can be an indicator of interest and motivation. It could also be a factor in whether the unit successfully teaches the benchmarks. If a student misses a day, he may miss information that won't be given on another day or miss practicing a skill that there will be no further opportunity to practice.

My grading policies are meant to encourage regular attendance. When students are absent and the absence is unexcused, they receive a zero for whatever was due that day. If a student is absent and the absence is excused, the student must make up the work. If he or she was absent 3 days, the due date for the made up work is three days after they return to class. Missed tests or quizzes must be made up before or after school. Homework quizzes are an exception since they are given orally. If the absence was excused, the student is excused from the homework quiz.

My policy on late work is meant to encourage responsibility. For the first marking period only, I accept late work but the grade is decreased by half. For the remainder of the year I don't accept late work with the exception of their notebooks of daily work. Those can still be turned in for 50% credit.

At the end of this unit, the day before the notebooks were due, many students talked about getting together to do all of the pages they had neglected to do during the unit. These were mainly homework assignments. From listening to the students I know that this mainly consists of students hand copying problems from a student who did them. It is a mechanical process with very little learning involved. This is one more example of poor work habits and another reason why grades are so low.

ANALYSIS OF GRADES AND ATTENDANCE

Looking at the data as a whole, one thing stands out. The scores are very low even when disregarding the zeros. The only tasks where the class average was above 77% were the two tasks that were graded on completion rather than accuracy. These were the notebook of daily work and the Prior Knowledge Survey. And as mentioned in the commentary section, many students did not do the work on a daily basis, but had a marathon session the night before the notebooks were due, copying from a student who did do the work.

Another pattern seems noteworthy. Students with scores of less than 80% definitely do not display mastery. A large percentage of the students received grades well below 80% on tasks that were graded on accuracy.

October 30 Homework Quiz: 29% (2 students) earned 90%,
71% (5 students) earned 70% or less
with their average being 50%.
November 13 Electricity Quiz: 33% (4 students) earned 80% or higher
with their average being 86.5%.
67% (8 students) earned 74% or lower

with their average being 44.5%.
November 29 Photovoltaic Post Lab: 8% (1 student) earned 88%.
92% (11 students) earned 71% or lower
with their average being 31%.
December 4 Electricity Test: 42% (5 students) earned 80% or higher
with their average being 87%.
58% (7 students) earned 77% or lower,
with their average being 69%.

Note that in the statistics above, I have not included scores of students who received zeros due to unexcused absences.

Students did show substantial gains in knowledge between the Prior Knowledge Survey and the post test. Therefore, the low grades earned on tasked are not likely due to an ineffective unit, but rather a reflection of the skills, work habits and cognitive abilities of some of the students as well as a lack of interest and motivation. I should point out that one major purpose of this thesis was to increase motivation. So when I say the unit was not ineffective, I mean in terms of showing gains on benchmarked knowledge. The unit appears to be ineffective in motivating students.

With the state of Michigan encouraging more students to take physics (the requirement is chemistry or physics) we are apt to continue to see classes where there are two distinct groups of students as there were in this class. It would not be in the best interest of society to drop the rigor to accommodate the group that consistently scores well below mastery. It would be better to continue to search for ways to motivate and encourage those lower performing students. Perhaps schools could offer courses of rigor in topics or fields that students value, presented in a way that spurs them to put forth greater effort.

APPENDIX IV THERMODYNAMICS ACTIVITIES

APPENDIX IV A
Questions to Accompany "Solar Hot Water A Primer"

1. List 6 ways to make your hot water system more efficient (besides switching to solar).

2. Why is a solar hot water heater system in Michigan more complicated than one you could have if you lived in Georgia?

3. What is the most common type of solar collector? (Be sure to look at the photo too.)

4. What type of solar water heater system would be the safest to use here in Michigan? What liquid circulates in the collector of this system?

5. List the advantages of the closed loop antifreeze heat exchanger system.

6. What do they mean by "powered by PV"?

7. List the disadvantages of the closed loop antifreeze heat exchanger system.

THERMODYNAMICS AND OPTICS UNIT
WEB ADDRESS FOR SOLAR HOT WATER ARTICLE

The students read this article and answered questions about it for homework. It was a way to introduce the topic using current information written for laypeople in the real world. The article was found at http://www.azsolarcenter.com/technology/solarh20/html. It was put out by the Arizona Solar Center and was titled "Solar Hot Water: A Primer." If this article is no longer available, this organization may have a more current replacement.

Questions to Accompany "Solar Hot Water A Primer"
TEACHER'S KEY

1. List 6 ways to make your hot water system more efficient (besides switching to solar).
   1. **Turn water heater thermostat down (suggestion 125 °F).**
   2. **Wrap hot water heater with insulating blanket (avoid burner).**
   3. **Fix leaky faucets.**
   4. **Use flow restrictors and aerators to reduce hot water consumption (like water-saver shower heads).**
   5. **Find other ways to use less hot water like doing only full loads of dishes in the dishwasher or washing clothes in warm or cold water instead of hot.**
   6. **Insulate hot water pipes. (Show students a foam pipe insulator.)**

2. Why is a solar hot water heater system in Michigan more complicated than one you could have if you lived in Georgia?
   Temperatures drop below freezing here. In climates where it doesn't freeze, the liquid in the manifold of the collector can be the same water that comes out of the hot water faucet. In Michigan we can't have water in the manifold because it would freeze solid in winter and break the manifold.

3. What is the most common type of solar collector? (Be sure to look at the photo.)
   Flat plate collectors are the most common type.

4. What type of solar water heater system would be the safest to use here in Michigan? What liquid circulates in the collector of this system?
   Closed-loop antifreeze heat exchanger is the safest. Propylene glycol, non-toxic antifreeze, circulates in the manifold of the collector.

5. List the advantages of the closed-loop antifreeze heat exchanger system.
   1. **Very good freeze protection.**
   2. **Well understood by plumbers.**
   3. **Hard water is not a problem, because you don't have water in the manifold.**
   4. **The pump can be solar powered.**

6. What do they mean by "powered by PV"?
   PV stands for photovoltaic. The pump that circulates the liquid can be powered by the sun.

7. List the disadvantages of the closed loop antifreeze heat exchanger system.
   1. **The system is complicated with lots of moving parts.**
   2. **It is not as efficient as other systems because heat has to be transferred from the antifreeze to the water.**
   3. **The antifreeze is not stable at the really high temperatures that result on days that the fluid doesn't circulate much.**

ANECDOTAL COMMENTARY ON SOLAR HOT WATER QUESTIONS

When we went over the answers to the homework questions, about half of the class raised hands and answered correctly. (The answers were all right in the article. There was no higher order thinking required.) One of the answers to question 1 was to insulate your hot water pipes, so I brought in a section of foam pipe insulation. I mentioned that they were available at most hardware stores or big box home improvement stores for just a couple of dollars.

APPENDIX IV B
SPECIFIC HEAT LAB FOR SOLAR COLLECTORS

Purpose: To find specific heats of various liquids to help determine which would be best suited for use in a solar collector.

Background Questions:

1. What characteristics would be desirable for this liquid?

2. Which of these characteristics are easily determined?

3. Common liquids used in solar collectors in cold climates are propylene glycol (a nontoxic antifreeze) and hydrocarbon oils. Pick one additional liquid you would like to test: ____________________________ . Pick which oil you would like to test: ____________________________ .

4. Record data of characteristics listed in number 2 above for the 3 liquids:

Propylene Glycol ________________Oil ____________________

5. Draw a labeled diagram of a closed-loop antifreeze heat exchanger system. Show cold water as blue, warm/hot water as red, and the liquid that absorbs the solar energy as yellow.

Materials:
- Bunsen burner (or hot plate)
- Ring stand
- Ring
- Clamp
- Wire Gauze
- String
- Scissors
- Aluminum sample
- 8-oz foam cup
- 100-ml graduated cylinder
- thermometer or temperature probe
- Goggles
- 200 ml your choice oil
- 200 ml propylene glycol (1,2-propanediol)
- 200 ml your choice liquid
- 600-ml beaker

Procedure:

1. Put 550 ml of tap water in a 600-ml beaker. Set over a Bunsen burner (faster) or hot plate (set on high). The water needs to be deep enough that the aluminum sample can be completely immersed without touching the bottom.
2. Mass the aluminum sample and record.
3. Tie a string to the aluminum sample. Dangle it down into the beaker of heating water. Wrap the string around the clamp to hold the sample at the correct height. (See figure 1.)
4. Look up the specific heat of aluminum and record.
5. After the water comes to a boil, leave the metal sample in the boiling water for 10 minutes. Why?

____

____

6. While waiting for the 10 minutes to pass, mass an empty foam cup or put it on a balance and zero the balance. Add 200 ml of propylene glycol to the cup. Record the mass of the propylene glycol.
7. Record the temperature of the propylene glycol in the foam cup as its initial temperature.
8. Record the temperature of the boiling water. This will be the initial temperature of the aluminum. Why can we assume this? ______________________________

   ____

9. After boiling for 10 minutes, remove the aluminum from the boiling water and dangle it in the liquid in the foam cup (calorimeter). Take care that it is completely immersed, but not touching the sides or bottom of the cup.
10. Stir the liquid gently with the thermometer and by gently swirling the aluminum. (See figure 2.) Even with stirring you should note a difference in temperature between the liquid at the top of the cup and the bottom. Why? ______________

    ____

    ____

11. When the temperature quits rising, record the temperature. Be sure to hold the thermometer halfway between the bottom and top of the cup to get an average temperature. This is recorded as the final temperature for the propylene glycol. It is also the final temperature for the aluminum. Why? __________________

    ____

12. Repeat steps 3 - 11 with your other two liquids. You may have to add more water to the boiling water beaker to insure that the aluminum can be completely submerged.

Data and Observations:

Mass of aluminum sample: _______________

Specific heat of aluminum: _______________

Mass of propylene glycol: _______________

Propylene glycol: T(initial): _______________ T(final): ______________

Aluminum: T(initial): _______________ T(final): ______________

Mass of ____________ oil: ______________

_______________ oil: T(initial): _______________ T(final): ____________

Aluminum : T(initial): _______________ T(final): ____________

Mass of ____________________: ____________ g

____________________: T(initial): ____________ T(final): ____________

Aluminum: T(initial): ____________ T(final): ____________

Calculations: $Q = mC\Delta T$

A. Specific Heat of Propylene Glycol

$$Q_{\text{lost by Aluminum}} = (m_{Al}) \quad (C_{Al}) \quad (\Delta T_{Al})$$

$$T_f \quad - \quad T_i$$

$$= (\qquad)(\qquad)(\qquad - \qquad)$$

$$Q_{\text{lost by Aluminum}} = \underline{\qquad\qquad\qquad} = Q_{\text{gained by propylene glycol}}$$

$$C_{\text{propylene glycol}} = \frac{Q_{\text{gained by propylene glycol}}}{(m_{\text{propglycol}})(\Delta T_{\text{Propglycol}})}$$

$$= \frac{\qquad\qquad}{(\qquad)(\qquad - \qquad)}$$

$$C_{\text{propylene glycol}} = \underline{\qquad\qquad\qquad\qquad}$$

$$\%\text{Error} = \frac{|\text{lab} - \text{accepted}|}{\text{accepted}} \times 100\% = \frac{|\qquad\qquad|}{\qquad} \times 100\% =$$

B. Specific Heat of ________________ Oil

(Follow the format of part A above)

C. Specific Heat of ______________________________

Question: Why can we say that the heat lost by the aluminum equals the heat gained by the liquid?

Analysis and Conclusion:

Write a paragraph in your OWN words (not your lab partner's words). **Be sure to have a statement which ties back to the purpose of the lab.** Include possible reasons for your percent error, ways the procedure or your technique could be improved, and ideas for follow-up studies. Tell what led you to choose these particular follow-up studies.

(Figure 1 on Student Copy)

Figure 83 Heating the Metal

(Figure 2 on Student Copy)

Figure 84 Heat Lost by the Metal is Gained by the Liquid

Specific Heat Lab
For Solar Collectors
Teacher's Key

Purpose: To find specific heats of various liquids to help determine which would be best suited for use in a solar collector.

Background Questions:

3. What characteristics would be desirable for this liquid?
   Low freezing point (on roof in Michigan in winter)
   Low specific heat (heat up quick, transfer heat quick)
   Nonviscous (flow through the system quickly and smoothly)
   Nontoxic (in case it leaks into the drinking water)
   High boiling point (It's temperature can never be hotter than boiling and we don't want steam – it would expand too much and blow a hole in the system.)
   Stable at high temperatures (Liquid in the manifold can get to over 200°C during periods where no one is drawing off hot water. Glycols can break down at that temperature, coating the insides of the pipes with the resulting thick sludge. Additives can make it more stable.)
   Inexpensive and readily available

4. Which of these characteristics are easily determined?
   Freezing Point: Look it up in CRC or Flinn catalog or on bottle's label.
   Boiling Point: Look it up as above, or heat to boiling and record temperature.
   Viscosity: Put some in a clear container and tip side to side.
   Toxicity: Look online or in Flinn catalog or on label of bottle.

3. Common liquids used in solar collectors in cold climates are propylene glycol (a nontoxic antifreeze) and hydrocarbon oils. Pick one additional liquid you would like to test: ____________________________ . Pick which oil you would like to test: ____________________________ .

4. Record data of characteristics listed in number 2 above for the 3 liquids:

<u>Propylene Glycol</u>   ______Oil__________   ____________________

Freezing Pt: -60°C
Boiling Pt: 187°C
Viscosity: Low
Toxicity: Non-Toxic

5. Draw a labeled diagram of a closed-loop antifreeze heat exchanger system. Show cold water as blue, warm/hot water as red, and the liquid that absorbs the solar energy as yellow.

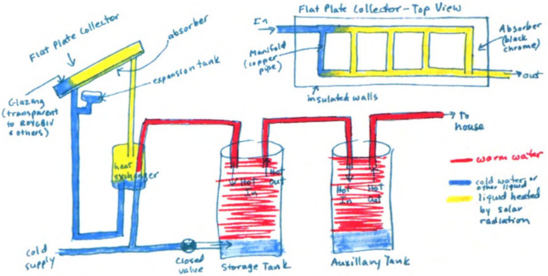


Figure 85 Closed-Loop Antifreeze Heat Exchanger System (teacher's drawing)

Materials:

- Bunsen burner (or hot plate)
- Ring stand
- Ring
- Clamp
- Wire Gauze
- String
- Scissors
- Aluminum sample
- 8-oz foam cup
- 100-ml graduated cylinder
- thermometer or temperature probe
- Goggles
- 200 ml your choice oil
- 200 ml propylene glycol (1,2-propanediol)
- 200 ml your choice liquid
- 600-ml beaker

Procedure:

9. Put 550 ml of tap water in a 600-ml beaker. Set over a Bunsen burner (faster) or hot plate (set on high). The water needs to be deep enough that the aluminum sample can be completely immersed without touching the bottom.
10. Mass the aluminum sample and record.
11. Tie a string to the aluminum sample. Dangle it down into the beaker of heating water. Wrap the string around the clamp to hold the sample at the correct height. (See figure 1.)
12. Look up the specific heat of aluminum and record.
13. After the water comes to a boil, leave the metal sample in the boiling water for 10 minutes. Why? **So that the metal will have time to come to thermal equilibrium with the boiling water.**

14. While waiting for the 10 minutes to pass, mass an empty foam cup or put it on a balance and zero the balance. Add 200 ml of propylene glycol to the cup. Record the mass of the propylene glycol.
15. Record the temperature of the propylene glycol in the foam cup as its initial temperature.
16. Record the temperature of the boiling water. This will be the initial temperature of the aluminum. Why can we assume this? __**Because the aluminum had come to thermal equilibrium with the boiling water.**__
9. After boiling for 10 minutes, remove the aluminum from the boiling water and dangle it in the liquid in the foam cup (calorimeter). Take care that it is completely immersed, but not touching the sides or bottom of the cup.
10. Stir the liquid gently with the thermometer and by gently swirling the aluminum. (See figure 2.) Even with stirring you should note a difference in temperature between the liquid at the top of the cup and the bottom. Why? __**Warm liquid is less dense, so more buoyant.**__
11. When the temperature quits rising, record the temperature. Be sure to hold the thermometer halfway between the bottom and top of the cup to get an average temperature. This is recorded as the final temperature for the propylene glycol. It is also the final temperature for the aluminum. Why? __**When the temperature quits changing at a fast rate, the aluminum has come to thermal equilibrium with the water.**__
12. Repeat steps 3 - 11 with your other two liquids. You may have to add more water to the boiling water beaker to insure that the aluminum can be completely submerged.

Data and Observations:

Mass of aluminum sample: ________________
Specific heat of aluminum: __**903 J/KgK**__

Mass of propylene glycol: ________________
Propylene glycol: T(initial): ________________ T(final): ______________
Aluminum: T(initial): ________________ T(final): ______________

Mass of __**canola?**__ oil: ____________
__**Canola?**__ oil: T(initial): ________________ T(final): ____________
Aluminum : T(initial): ________________ T(final): ____________

Mass of __**Student's Choice**__: ____________ g
__**Student's Choice**__: T(initial): ____________ T(final): ____________
Aluminum: T(initial): ____________ T(final): ____________

Calculations: $Q = mC\Delta T$

A. Specific Heat of Propylene Glycol

$$Q_{\text{lost by Aluminum}} = (m_{Al}) \quad (C_{Al}) \quad (\Delta T_{Al})$$

$$T_f \quad - \quad T_i$$

$$= (\qquad)(\qquad)(\qquad - \qquad)$$

$$Q_{\text{lost by Aluminum}} = \underline{\qquad\qquad\qquad} = Q_{\text{gained by propylene glycol}}$$

$$C_{\text{propylene glycol}} = \frac{Q_{\text{gained by propylene glycol}}}{(m_{\text{propglycol}})(\Delta T_{\text{Propglycol}})}$$

$$= \frac{\qquad\qquad}{(\qquad)(\qquad - \qquad)}$$

$$C_{\text{propylene glycol}} = \underline{\qquad\qquad\qquad\qquad}$$

$$\%\text{Error} = \frac{|\text{lab - accepted}|}{\text{accepted}} \times 100\% = \frac{|\qquad\qquad|}{\qquad} \times 100\% =$$

B. Specific Heat of _________________ Oil

(Follow the format of part A above)

C. Specific Heat of ______________________________

Question: Why can we say that the heat lost by the aluminum equals the heat gained by the liquid?
The heat has to go somewhere. If the metal is completely immersed in the liquid, there is no where for the heat to go except into the water. But note that eventually some of the heat gained by the water will be lost out into the air or gained by the foam cup. However, the amount is negligible due to the imprecision of the thermometer.

Analysis and Conclusion:

Write a paragraph in your OWN words (not your lab partner's words). **Be sure to have a statement which ties back to the purpose of the lab.** Include possible reasons for your percent error, ways the procedure or your technique could be improved, and ideas for follow-up studies. Tell what led you to choose these particular follow-up studies.
Possible response:
We concluded that _____________ would be the better option for a solar collector. It has a lower specific heat so would heat up quickly before it circulated out of the collector, and it would transfer its heat quickly to the water in the heat exchanger. One reason for the large percent error of ____% could be due to the aluminum sticking up above the surface of the propylene glycol. It should have been totally immersed. Some of the heat it lost did not go into the water. Using more propylene glycol could solve that problem for future trials. A logical follow-up study would be to put the hot liquids in a tube, flow the tubes through water and see how much the water temperature changes. We chose this idea because it actually simulates the environment in a solar hot water system.

ANECDOTAL COMMENTARY ON THE SPECIFIC HEAT LAB

Students came up with a lot of great ideas for characteristics that would be desirable for the liquid in the manifold of a solar collector. They seemed to enjoy the brainstorming and problem solving aspects and acted proud when they came up with an idea. One student came up with important considerations I had not thought of – that the liquid be inexpensive and easy to get. I added those to my teacher's key. There was a lot of verbal participation from the class as a whole for the second background question also, "Which of these characteristics is easily determined?"

Students also seemed to have fun coming up with ideas for the third liquid to test. Some suggested Gator Aid. We talked about it being mostly water. They decided that would pose a problem as it could freeze during the winter months. Other ideas that students came up with included salt water, rubbing alcohol and an ethylene glycol-alcohol mix. Ethylene glycol is regular antifreeze so it is cheap and readily available. We discussed the fact that if some kind of a leak developed in the heat exchanger vicinity, the poisonous liquid in the manifold would get into the household water. They decided that the extra cost of the non-toxic propylene glycol would be worth it for safety reasons.

At the end of class that day students had a few minutes to look up the characteristics of the liquids they chose to test. I had Flinn catalogs, the CRC Handbook of Chemistry and Physics and two computers available.

The day that we performed the lab, students had time to test only two substances. and some of those students still had to get late passes to their next class.

The next morning one student came in before school to get help on the calculations for the lab. I asked her if she remembered using the formula in chemistry. She said she had

had chemistry two years ago and didn't remember thermochemistry at all. I guided her through the calculations.

The lab was due the next morning. None of the students had looked up the accepted values for specific heats. They needed that information to be able to calculate percent error. I wrote the accepted values on the board and told them they had a couple of minutes to do the percent error calculations. Most students had trouble with this calculation.

A fire drill interrupted us before the students finished the calculations. Some of them lost their focus. And the drill itself added to the time lost over having to spend time helping them with the math. So overall, the lab took about 40 minutes longer than I had planned, including the time it would have taken to test the third liquid.

APPENDIX IV C
FOUR ARTICLES ON ABSORBANCE AND SOLAR HEATING

WEB ADDRESSES

1. Experimental Evaluation of a Single-Basin Solar Still Using Different Absorbing Materials. 2006.
   Written by Akash , B. A., et al.
   Journal of Renewable Energy, ISSN 0960-1481
   To view article: http://cat.inist.fr/?aModele=afficheN&cpsidt=1593496

2. Solar Heat Selective Absorbing Material and its Manufacturing Method
   Abstract of patent
   Inventors: Kagechi and Fujimoto
   Filing date: 10/19/1987
   To view abstract: http://www.freepatentsonline.com/4937137.html

3. Sustainable Design, Zero-Energy, Passive Solar, High Thermal Mass HTM, Practical Earth Home Construction
   Consultation for homeowner-builders
   To view article: http://www.thenaturalhome.com/passivesolar.html
   This is a commercial site that sells home building supplies.
   I printed off only page one for the students.

4. Solar Energy for Homes
   NESEA
   To view article: http://www.nesea.org/buildings/passive.html
   All six pages are good. The best parts for the lesson plan are on pages 5 and 6 under "Sun Spaces".

ANECDOTAL COMMENTARY

For articles 1,2 and 3, I gave students only the first page. I gave them all six pages of the fourth article. Some of the articles were very technical, but I wanted to expose them to a real journal article and a real patent. They could compare those to the two that were written more for the general public.

The copies I gave the students had arrows, brackets and handwritten notes telling them which parts to focus on. I figured if I did not do that, many students would immediately feel overwhelmed. Students were asked to skim the articles and highlight with yellow the parts they felt were most important or that they found most interesting. During reading and highlighting, six of the students took their time and read every word. I am assuming that is because the articles interested them.

APPENDIX IV D
ABSORBANCE AND EMISSION
HEATING SOLAR SPACES

Purpose: To evaluate various materials for their suitability as materials for solar space heating applications.

Background: In the solar collector there is an absorber plate that absorbs electromagnetic radiation from the sun and then emits infrared waves back into the collection box. In architecture, construction materials can be used to soak up the electromagnetic waves. Ideally the material will cool slowly and continue emitting heat all through the night to warm the air in the room, which can be blown into the rest of the house as needed. A room built especially for this purpose (normally on the south side of the house) is often called a solar space or solar room.

1. The sun emits all frequencies of the electromagnetic spectrum. Sketch the spectrum below . Label which end is high/low frequency, long/short wavelength and high/low energy. Circle the wave type whose common name is "heat".

2. Draw, using a pencil, not a pen, a glass room on the south side of a house. Use arrows to represent electromagnetic waves:
    a) reflecting off the transparent material
    b) being refracted by the transparent material
    c) exiting the opposite side of the transparent material
    d) reflecting off the construction materials inside the room
    e) being absorbed by the construction materials inside the room
    f) exiting the opposite side of the construction material
    g) being emitted by the construction material

**Label the arrows with the frequencies that they represent.

3. Considering the drawing you made in number 2 above,
    a) What effect does the transparent media (glass, plastic, etc) have on the light rays?

    b) Which frequency are we attempting to maximize and harvest?

    c) Why is it beneficial for the transparent media to absorb or reflect IR and not beneficial for it to transmit IR?

    d) What effect to the construction materials have on the light rays?

    e) What properties of materials affect the amount of infrared that can be harvested?

4. a) In the case of a solar collector, do you want the absorber to heat up/cool down fast or slow? Why?

   b) In the case of the solar room, do you want the construction materials to heat up/cool down fast or slow? Why?

   c) Materials with a high specific heat would be best for:

   d) Materials with a low specific heat would be best for:

   e) How can you minimize loss of infrared waves from the collector or solar room?

Discuss and go over 1-4.

With your group, decide on 3 materials that you would like to test.

Do the questions under the materials section.

Get teacher approval for your 3 materials.

Materials:

- 3 plastic dishpans (tubs)
- 3 digital thermometers
- Foam to fit around edges of tubs
- Scissors
- Balance (that can accommodate the heavy weights)
- Tape measure or ruler
- 3-12x14" pieces of glass or Transparent plastic
- Aluminum foil
- Black cloth or black spray paint (your choice)
- 3 materials (your choice)
- Containers for materials if at least one requires a container
- Time piece
- Cardboard, wood or thick cloth capable of covering all 3 tubs at once

Materials Questions:

1. If you are trying to have only one variable (the identity of the material) and the materials are two different colors, how can you eliminate the unwanted variable?

2. What other variables do you need to eliminate?

Discuss volunteers for collecting data outside of class. See number 10 under procedure.

Procedure:

1. Attempt to get your 3 construction materials as close to the same mass as possible. Record the final mass of each.
2. Find 3 digital thermometers that read the same temperature (or as close to the same temperature as possible).
3. Line 3 dishpans with aluminum foil.
4. Set the 3 dishpans outside where they will receive full sun and no shadow until sunset.
5. Lay a different construction material in the bottom of each one. Put a masking tape label in plain view inside each tub. It should include your names and the type of material.
6. Wrap the material in black cloth if you have not otherwise corrected for color differences.
7. Put foam around the edges of the dishpans and lay the transparent glazing (glass or plastic) over the top. Be sure there are no air holes. (Photo on last page.)

8. Record the temperature shown on all three thermometers before placing them in the dishpans.
9. Insert the probes between the foam and the tub edge, being careful that they are oriented in the same way in each tub. Record the temperatures and the time.
10. Take temperature readings every 3 minutes for 24 minutes.
11. (If no one can come in to take readings during the evening and before sunrise, cover all three tubs with wood, cardboard, or cloth and continue to take readings for the remainder of the class period as the system cools down.)
12. If someone will be coming in to take readings when the sun is not up, just continue to take readings for the remainder of the class period.

13. Volunteers to collect temperature readings on ALL tubs:

	Today	Tomorrow
After 1st Hour	____________________	____________________
2nd Hr	____________________	____________________
3rd Hr	____________________	____________________
4th Hr	____________________	____________________
5th Hr	____________________	____________________
6th Hr	____________________	____________________

After School: ____

After Sports etc: ____

After Dark: ____

Before Sunrise: ____

14. Day 2 in class: Record data that other students took for you.

<u>Data and Observations</u>: (Record in pen. Correct errors in recording by drawing a single line through the error so it is still readable.)

Analysis of Data:

Use the temperature data to plot a line graph on graph paper of all three boxes on the same graph. Calculate slopes (rate of change of temperature) below. Note other differences or similarities in the three sets of data. Show calculations below. Attach the graph paper.

Conclusion:

Write a paragraph or two in your OWN words which ties back to the purpose of the lab. Incorporate optics vocabulary. Be sure to use your analysis of the empirical data to back up the claim you make in the conclusion. Include which absorption, transmission, reflection, emission properties would be ideal for the absorber in a solar collector, construction materials to absorb heat in a solar room, glazing on a collector, and the window of the solar room. Also include all other requirements mentioned in our sheet on Format for a Lab Write-Up.

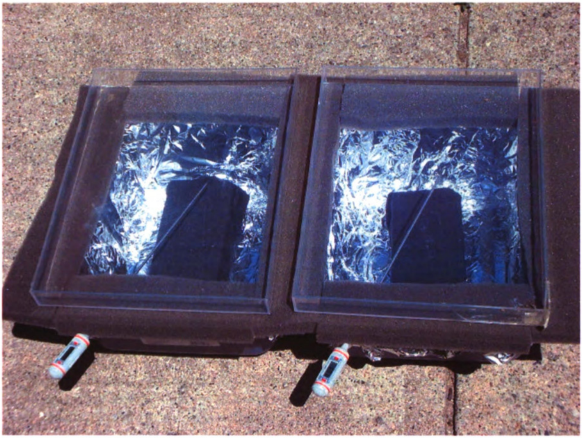


Figure 86 Solar Collectors with Black Absorbers

TEACHER'S KEY

Absorbance and Emission Lab
Heating Solar Spaces

Purpose: To evaluate various materials for their suitability as materials for solar space heating applications.

Background: In the solar collector there is an absorber plate that absorbs electromagnetic radiation from the sun and then emits infrared waves back into the collection box. In architecture, construction materials can be used to soak up the electromagnetic waves. Ideally the material will cool slowly and continue emitting heat all through the night to warm the air in the room, which can be blown into the rest of the house as needed. A room built especially for this purpose (normally on the south side of the house) is often called a solar space or solar room.

1. The sun emits all frequencies of the electromagnetic spectrum. Sketch the spectrum below. Label which end is high/low frequency, long/short wavelength and high/low energy. Circle the wave type whose common name is "heat".

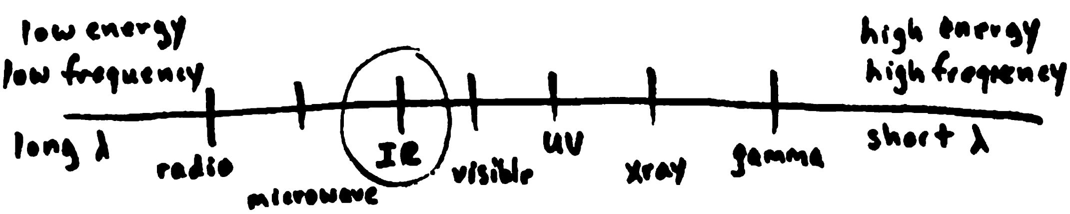


Figure 87 Electromagnetic Spectrum (teacher's drawing)

2. Draw, using a pencil, not a pen, a glass room on the south side of a house. Use arrows to represent electromagnetic waves:
   a. reflecting off the transparent material
   b. being refracted by the transparent material
   c. exiting the opposite side of the transparent material
   d. reflecting off the construction materials inside the room
   e. being absorbed by the construction materials inside the room
   f. exiting the opposite side of the construction material
   g. being emitted by the construction material

**Label the arrows with the frequencies that they represent.

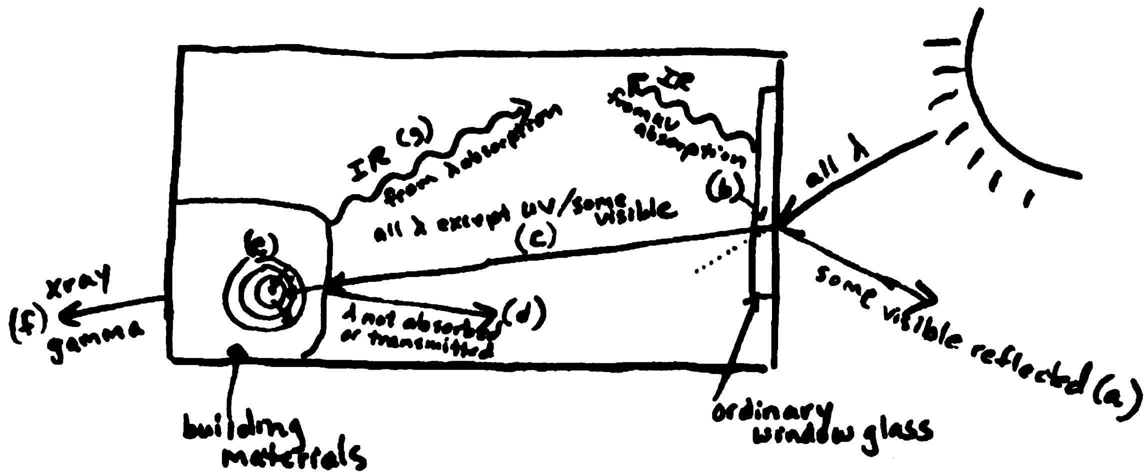


Figure 88 Optics in a Glass Room (teacher's drawing)

3. Considering the drawing you made in number 2 above,
   a. What effect does the transparent media (glass, plastic, etc) have on the light rays? **It absorbs UV, reflects some visible, and refracts the frequencies that are transmitted through. So the transparent media determines which frequencies enter the room.**

   b. Which frequency are we attempting to maximize and harvest?
   Infrared

   c. Why is it beneficial for the transparent media to absorb or reflect IR and not beneficial for it to transmit IR? **The absorber absorbs a wide range of frequencies and radiates them all back out as IR (heat). We want them to stay trapped in the collector or room. The amount of IR being blocked from entering is a small amount in comparison.**

   d. What effect to the construction materials have on the light rays?
   It determines the percentage of incoming solar frequencies that can be that can be absorbed and radiated as heat. It also determines how much heat can be stored and at what rate it will be radiated.

   e. What properties of materials affect the amount of infrared that can be harvested?
   Specific heat, optical properties of transmittance, reflectance, and absorbance which are dependent upon the natural frequency of of the electrons in the atoms of the substance.

4. a) In the case of a solar collector, do you want the absorber to heat up/cool down fast or slow? Why?
   If it happens quickly, the heat can be transmitted to the water in a short amount of time, but it would not retain heat to be able to transmit when clouds passed overhead.

   b) In the case of the solar room, do you want the construction materials to heat up/cool down fast or slow? Why?
   If the materials cool down slowly, they would radiate heat all night long and keep the room warm.

   c) Materials with a high specific heat would be best for:
   Situations where there is a long period of time available for soaking up energy, and/or where you want it to radiate heat back out over a long period of time. Example: A solar room.

   d) Materials with a low specific heat would be best for:
   Situations where the material has a short amount of time to absorb energy, or needs to radiate heat over a short amount of time. Examples: absorber in a collector, heat exchanger in a hot water system or on the outside of a building (air flows by it quickly).

   e) How can you minimize loss of infrared waves from the collector or solar room?
   Insulate the walls, ceiling and floor and use a transparent window that does not transmit IR.

Discuss and go over 1-4.

With your group, decide on 3 materials that you would like to test.

Do the questions under the materials section.

Get teacher approval for your 3 materials.

Materials:

- 3 plastic dishpans (tubs)
- 3 digital thermometers
- Foam to fit around edges of tubs
- Scissors
- Balance (that can accommodate the heavy weights)
- Tape measure or ruler
- 3-12x14" pieces of glass or Transparent plastic
- Aluminum foil
- Black cloth or black spray paint (your choice)
- 3 materials (your choice)
- Containers for materials if at least one requires a container
- Time piece
- Cardboard, wood or thick cloth capable of covering all 3 tubs at once

Materials Questions:

1. If you are trying to have only one variable (the identity of the material) and the materials are two different colors, how can you eliminate the unwanted variable?
   Possible answer: Spray paint them the same color.

2. What other variables do you need to eliminate?
   Mass: You might be able to break it into pieces and use the piece that is the desired mass.
   Surface Area: Some objects can be broken into pieces to create more surface area, or they can be arranged differently to have more or less of their surface area exposed to the sun. However, when radiating heat, even the surfaces not facing the sun need to be equivalent.

Discuss volunteers for collecting data outside of class. See number 10 under procedure.

Procedure:

1. Attempt to get your 3 construction materials as close to the same mass as possible. Record the final mass of each.
2. Find 3 digital thermometers that read the same temperature (or as close to the same temperature as possible).
3. Line 3 dishpans with aluminum foil.
4. Set the 3 dishpans outside where they will receive full sun and no shadow until sunset.
5. Lay a different construction material in the bottom of each one. Put a masking tape label in plain view inside each tub. It should include your names and the type of material.

6. Wrap the material in black cloth if you have not otherwise corrected for color differences.
7. Put foam around the edges of the dishpans and lay the transparent glazing (glass or plastic) over the top. Be sure there are no air holes. (Photo on last page.)
8. Record the temperature shown on all three thermometers before placing them in the dishpans.
9. Insert the probes between the foam and the tub edge, being careful that they are oriented in the same way in each tub. Record the temperatures and the time.
10. Take temperature readings every 3 minutes for 24 minutes.
11. (If no one can come in to take readings during the evening and before sunrise, cover all three tubs with wood, cardboard, or cloth and continue to take readings for the remainder of the class period as the system cools down.)
12. If someone will be coming in to take readings when the sun is not up, just continue to take readings for the remainder of the class period.

13. Volunteers to collect temperature readings on ALL tubs:

	Today	Tomorrow
After 1st Hour	____________________	____________________
2nd Hr	____________________	____________________
3rd Hr	____________________	____________________
4th Hr	____________________	____________________
5th Hr	____________________	____________________
6th Hr	____________________	____________________

After School: ____

After Sports etc: ____

After Dark: ____

Before Sunrise: ____

14. Day 2 in class: Record data that other students took for you.

<u>Data and Observations</u>: (Record in pen. Correct errors in recording by drawing a single line through the error so it is still readable.)

<u>Analysis of Data</u>:

Use the temperature data to plot a line graph on graph paper of all three boxes on the same graph. Calculate slopes (rate of change of temperature) below. Note other differences or similarities in the three sets of data. Show calculations below. Attach the graph paper.

Conclusion:

Write a paragraph or two in your OWN words which ties back to the purpose of the lab. Incorporate optics vocabulary. Be sure to use your analysis of the empirical data to back up the claim you make in the conclusion. Include which absorption, transmission, reflection, and emission properties would be ideal for the absorber in a solar collector, construction materials to absorb heat in a solar room, glazing on a collector, and the window of the solar room. Also include all other requirements mentioned in our sheet on Format for a Lab Write-Up.

ANECDOTAL COMMENTARY ON ABSORBANCE AND EMISSION LAB

When designing the activities for this unit, this lab took the most time to develop. I tried many different combinations of equipment and materials for the collector box, absorber, glazing and insulation. At first there were not significant differences in temperature between the control collector and the variables.

Taking temperature data also posed a problem at first. If the digital thermometer was inside the unit, the digits in the display shut off after a period of time. They could not be turned back on without opening the collector by lifting the glazing and losing heat. I tried putting different types of insulation between the glazing and box and sticking the probe through the insulation so that the on/ff button and digital display were outside the box. That introduced a lot of variation between boxes as it was hard to get identical placement of the insulation in all collectors. When the students were doing the lab I hit upon the idea of poking a hole in the collector box the diameter of the probe and sticking the probe in through the hole. They used a nail to make the hole. That seemed to work very well with minimal air space for heat loss. About half of the groups used that method.

Another discovery I had made during my trials over the summer, was that lining the collector boxes with aluminum foil resulted in much greater buildup of heat inside. All of the groups ended up using that technique. Likewise, I found that the color of the absorber was almost as important as how massive it was. I shared that information with the students and most of the groups spray painted their absorbers black. One very creative girl was using natural clay for an absorber. She made her other absorber, which was a rock, the same color by rubbing the rock all over with a small piece of clay.

In developing this lab I also did quite a bit of experimentation with the glazing. After trying plastic and regular window glass I wanted to see what kind of results I could get with the IR –blocking glass which was mentioned in quite a few articles on solar collection. However, the only samples I could find in catalogs and on the web were prohibitively expensive unless they were the size of a microscope lens. Searching further on the web, I found that big box building supply stores carry an IR-blocking film that can be applied to regular window glass. It is meant to be used on the south side of buildings to keep the rooms cooler by blocking heat waves from entering. I wanted to use it to keep the IR radiated by the absorber inside the collector from escaping back out. I succeeded only in keeping the collectors cooler (not my goal), and when I put them in the shade I saw no evidence that the glazing was keeping the radiated IR from escaping. I tried insulating the sides and bottom of the collector in case the heat loss was occurring there.

I realize now that I should have tried putting the IR-blocking film on the inside of the glazing, or tried laying it over the collector only after they were taken out of the sun! I will try that next year for my experiment when the students are doing theirs.

The day we started the lab we first read and discussed the four articles on absorbance. That left only enough time to read the purpose and background, and to do the drawing of the electromagnetic spectrum (which is #1 under the background section). Many of the students had misconceptions about the relative energies.

On the second day of the lab students seemed pretty interested in the lecture on what happens when wavelengths hit an object and are absorbed. No one complained about taking notes and many students responded with correct answers whenever I asked questions during the lecture to check their understanding. Students were also able to volunteer correct answers when filling in #3 and #4 of the background questions on the lab.

When discussing what materials their group would like to test as absorbers, students asked relevant questions. "How large is the box that we will use for the collector?" "Would a wooden spoon be ok?" I reminded that group that the mass was very important. they decided that the spoon would probably not be able to store and emit very much heat.

The students engaged in a lot of discussion concerning which materials to try for the absorber. I brought up the problem of trying to study a single variable when the various absorbers differ in both mass and surface area. The students decided it was indeed a conundrum. Their discussion led to brainstorming ways to measure densities and surface areas of things that are oddly shaped like a pile of straw. One girl suggested finding the surface area of one piece of straw, and then multiplying it by the number of pieces. The same student also voiced this brilliant comment, "Just because a stacked pile of cardboard has the same general outer dimensions as a brick, the sides would have corrugation, so more surface area to emit heat." (This seems extra insightful as it comes on the heels of the class agreeing that the surface area that matters as far as absorption is only the surface that faces the source of radiation. She took it another step further and was thinking ahead about the object later emitting IR in all directions from all of its surfaces.

It was hard getting students to volunteer to collect temperature data between classes and after school. I think the reluctance on the part of students may have had to do with their other teachers giving them a hard time.

The day we performed the lab we had to start the period by going outdoors to spray paint the absorbers since only one person had brought theirs in the day before. During that period students were only engaged when it was their turn to spray. A lot of time was wasted.

When we got back inside, all of the students became very busily involved lining tubs with aluminum foil and getting their collectors put together. By the time we got our collectors outside it was partly cloudy. Students took readings and notated the cloud cover. The few students that did sign up to take temperature readings all showed up and did a careful job. I went out with them to observe.

APPENDIX IV E
BOILING WATER LAB

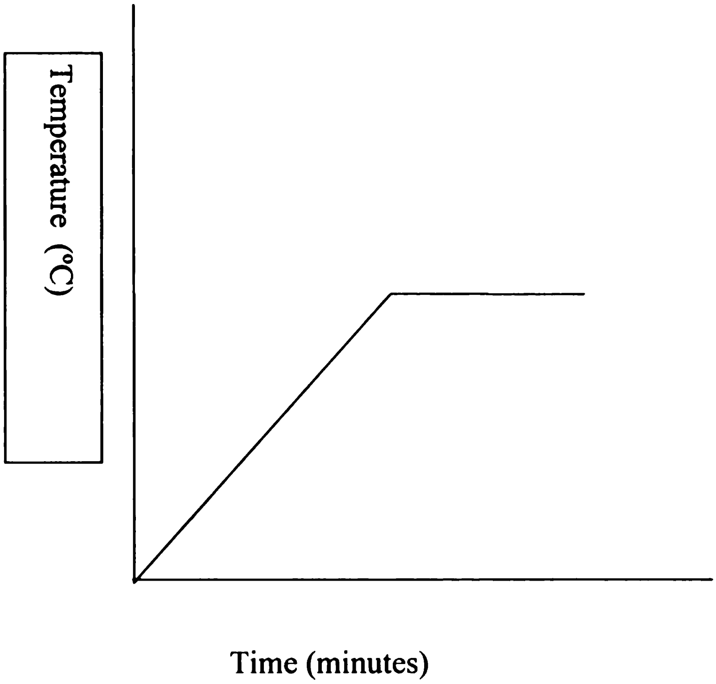
DESCRIPTION

The following directions were put up on an overhead. Hot plates, beakers and thermometers had already been laid out on the lab benches. Students used classroom clocks for time measurement.

1. Fill a beaker half full of tap water and heat it on the hot plate. Set the temperature dial to the highest setting.
2. Take temperature readings every one minute until the water has been boiling for three minutes.
3. While waiting to take temperature readings, make a data table where you can record the temperatures and times.
4. Graph the data on a temperature versus time graph.

BOILING WATER LAB TEACHER'S KEY AND DISCUSSION

Shape of the Graph



Discussion

1. How do you know when the water is boiling?
   The temperature quits changing. (Don't tell them the answer if they don't say it. Just move on to #2.)

2. Have a student draw the shape of his or her graph on the board.

3. Where on the graph is the water actually boiling?
   The horizontal section.

4. Why is the graph horizontal there?
   Because the temperature has quit changing. All of the heat being applied to the water is being used for the phase change. None of it is being used to warm the water.

5. At what temperature did this occur? **(Be suspicious if they all say 100°C.)**

6. Why was it not right at 100°C for most of you? **Inaccurate, cheap thermometers and impurities in the H_2O.**

ANECDOTAL COMMENTARY ON THE BOILING WATER LAB

During the lab there were a lot of heated discussions within groups about when to quit taking temperature readings. The arguments had to do with whether or not the water was boiling. Some students insisted that as soon as they saw a few bubbles form against the bottom of the beaker the water was boiling. Other students were adamant that it couldn't be boiling unless the thermometer read 100°C.

I heard some students grumbling about how stupid it was to stand there recording temperatures of water, what a waste of time it was. One boy got so disgusted that he left the lab station and sat down at his desk, refusing to participate.

A few minutes later one group voiced frustration. "Our water just won't boil. It's stuck at 99.6 degrees!" I walked by several groups whose water was boiling vigorously and asked how long their water had been boiling. "It's not boiling yet. It's not up to 100 degrees."

During the class discussion of the temperature graph following the lab, the concept finally clicked for several students. It became clear to them that the evidence that water was boiling (going through a phase change) was when the temperature quit changing. We talked about the heat from the hot plate being used transform the liquid to a gas rather than being available to heat the liquid.

APPENDIX IV F
QUESTIONS ON STIRLING ENGINES
TO ACCOMPANY *SUNCATCHERS TUNED TO CRANK OUT THE JUICE*

STUDENT COPY

1. The Stirling engine was invented by _______________ ____________________ in ____________________ .

2. The engine can convert ____________________ to ________________________ which turns an alternating current ______________________ .

3. The US Department of Energy predicts that by 2011, Stirling solar dish farms could deliver electricity to ______________________ at costs comparable to ____ .

4. An 11-square mile farm of Stirling solar dishes could generate as much electricity as ________________________________ . A 100-mile by 100-mile square farm could supply ____ .

5. The Stirling engine is a heat engine. The source of heat for the hot reservoir in the Stirling solar dish engine comes from ____________________________________ ____ .

6. What are the 3 design areas that engineers are working on improving?

TEACHER'S KEY
QUESTIONS ON STIRLING ENGINES
TO ACCOMPANY *SUNCATCHERS TUNED TO CRANK OUT THE JUICE*

****Ask students what DOE stands for.**

1. The Stirling engine was invented by ______Robert Stirling________________ in ____1816_____ .

2. The engine can convert ____solar heat__ into _______mechanical energy___ which turns an alternating current _____generator_________.

3. The US Department of Energy predicts that by 2011, Stirling solar dish farms could deliver electricity to ____the grid___________ at costs comparable to ________conventional_electrical_sources______.

4. An 11-square mile farm of Stirling solar dishes could generate as much electricity as _____Hoover_Dam_____________ . A 100-mile by 100-mile square farm could supply ____enough electricity for all day time needs in the US____________ .

5. The Stirling engine is a heat engine. The source of heat for the hot reservoir in the Stirling solar dish engine comes from __solar rays focused by mirrors into a____ ______________________concentrated beam____________ .

6. What are the 3 design areas that engineers are working on improving?

   1. **A system to turn the mirrors toward the sun as the sun changes position and in a position that protects them from damage when it is windy.**

   2. **A system that maintains a steady rpm of 1800 which is most efficient, by adjusting the flow between the hot and cold reservoirs.**

   3. **A system that staggers the start-up times of the engines so that they are not all coming online at the same instant.**

WEB ADDRESS FOR "SUN CATCHERS TUNED TO CRANK OUT THE JUICE"

This article was given to student to read along with a sheet of questions to accompany it. If this particular article is no longer available there should be updated information in other articles put out by the Department of Energy as they are continually working on this project.

Web address of the article:

http//www.eetimes.com/news/latest/showArticle.jhtml?articleID=53700939

ANECDOTAL COMMENTARY ON QUESTIONS ON STIRLING ENGINES

The same students who were disinterested or hostile (perhaps overwhelmed?) by the earlier journal article showed little interest in this one. When we went over the answers to the questions only two students consistently called out the answers. Like the other articles, filling in the answers to the questions required no critical thinking. The answers were given in the text of the article. However, students may have had to think hard while reading to digest what they were reading.

APPENDIX IV G
BUILDING A STIRLING ENGINE

Extra Credit
Rubric for the Stirling Engine

DUE: ____________________

3	1. Hand-drawn illustration of the finished model and any intermediate steps that would be necessary for communicating how to build the engine.
1	2. List of materials used.
18	3. Log of the amount of time spent on each step. 1 point per 10 minutes 18 point maximum
5	4. Demonstration to the class that your engine works.
5	5. Extra points if you use solar energy to heat the hot reservoir.

____

32 possible

WEBSITE FOR BUILDING A STIRLING ENGINE

The following websites show plans that students could use for building a Stirling engine. However, it would probably be best to have students search the web themselves to find plans.

http://rotarystirlingengines.com/rotacola_m.htm

http://www.geocities.com/therecentpast/?200726

http://bekkoame.ne.jp/~khirata/english/mk_can.htm

ANECDOTAL COMMENTARY ON BUILDING A STIRLING ENGINE

After explaining the extra credit project to the class, I asked how many were interested. Eleven of the 13 students raised their hands indicating that they wanted a copy of the rubric. They had three weeks to work on it at home.

One student did the project. During the presentation he pointed out the various parts of his engine, described what their function was supposed to be and went into detail about which parts did not function as they should. He described the tweaking he had done while attempting to get each part to perform its function.

In this boy's model, the greatest obstacles were the friction between the moving parts and leakage of air out of the system. He tried using extra hot glue around joints and wrapping the can in aluminum foil. But there was still too great a loss of pressure. He used a candle flame for the hot reservoir and room temperature air for the cold reservoir.

APPENDIX IV H
PAYOFF TIME HOMEWORK

EXPLANATION OF PAYOFF TIME HOMEWORK

This assignment was put up on an overhead.

1. Research the average payoff time in Michigan for a:

    a. closed-loop antifreeze water heating system

    b. geothermal heat pump
    (hint: earthcomfort.com helps calculate this one.)

2. Are there tax credits available for either one that would influence the payoff time?

3. Document your sources and attach any articles from the web. The attached article is your documentation for any web sources.

10 points Due ______________________ .

ANECDOTAL COMMENTARY ON PAYOFF HOMEWORK

Two days before the homework assignment was due, one student asked what I meant by average payoff time. This gave me the chance to clarify the meaning for the whole class. I wouldn't have guessed that the term would be unknown to them.

The day before the assignment was due three students mentioned something pertaining to the assignment. "I couldn't find anything specifically on closed-loop antifreeze systems." I asked if they had tried ask.com and got the students brainstorming briefly about what key words could be tried in the search. "Is it okay to highlight the information on payoff time (on the article), or do we have to write it out in sentences?" I told the class I wanted it written out in sentences, but that it would be helpful to me in grading if they could also highlight the information in the article. Another student followed up with the comment, "I highlighted the paragraphs of interest and did the payoff in another color so it stood out."

APPENDIX IV I
BUILDING ROCKETS (TINY HEAT ENGINES)

DESCRIPTION

The students were given a handout of directions I had found on the web. (http://sci-toys.com/scitoys/scitoys/thermo/thermo.html). I gave them pages 14 through 18 only.

The materials needed are common and inexpensive: book matches, aluminum foil, a paper clip, a straight pin and a lighter. The lighter should be the type with a long barrel that is turned on using a gun-like trigger.

The student lays a match head on a small strip of aluminum foil. A paper clip is unfolded and its end set up against the match head. That way when the match head is rolled up in the aluminum foil, there is a little passageway created. the foil is twisted shut on each end of the match head. (See my photos.) It takes a lot of care not to tear the foil when twisting it. The object is to create an airtight space, except for the passageway. Excess foil on the end away from the paperclip is cut off. The paper clip is then removed.

A launch pad is made by crumpling a piece of aluminum foil around the head of a straight pin. The ball is about the diameter of a nickel or quarter. The pin is situated in it so that at least half of the pin is sticking out and pointed at a 45° angle to the floor. The passageway created by the paper clip slides down over the exposed pin. A lighter is then held under the match head. The match head ignites and the rocket zooms off!

PHOTOS OF BUILDING ROCKETS (TINY HEAT ENGINES)

Figure 89a Materials: Aluminum foil, scissors, matches, paper clip, lighter, straight pin.

Figure 89b Cut a small strip of foil, and cut the head off a match.

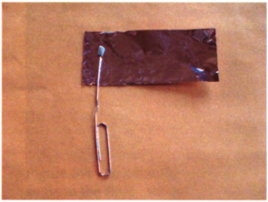


Figure 89c Lay match head on foil with paper clip end touching match head.

Figure 89d Fold foil over match head and paper clip, pressing snugly.

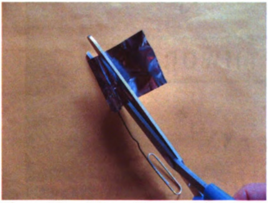


Figure 89e After rolling the foil around match and clip a few times, cut the excess foil off.

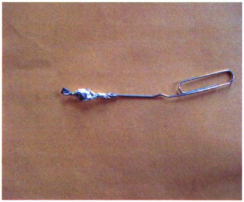


Figure 89f Carefully twist the foil tightly around the clip and match head.

Figure 89g Cut the excess off end opposite of tail pipe so it flies smoothly.

Figure 89h Put the head of the pin inside a wadded up ball of foil.

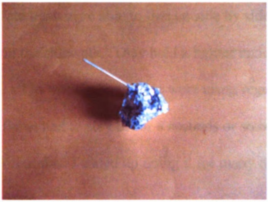


Figure 89i Position the pin at a 45° angle to the floor and wad the ball up tightly.

Figure 89j Slide the tail pipe that was created by the paper clip, down over the pin.

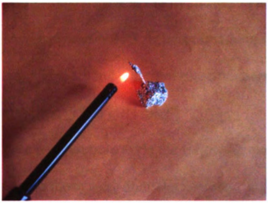


Figure 89k Position the flame under the match head until it ignites and shoots off!

ANECDOTAL COMMENTARY ON BUILDING ROCKETS (TINY HEAT ENGINES)

All students were totally engrossed in making the rockets. About half had trouble following the directions even with the photos, so I went around to each group demonstrating the different steps. It is crucial that there are no tears in the foil in the compartment enclosing the match head. It is very easy to tear the foil without realizing it when twisting. Some tears aren't apparent even upon close visual inspection. I had each student make 5 rockets so that they were likely to have at least one that worked well.

The contest took place outside on a section of sidewalk that was about 20 feet wide. The students were able to line up side by side on the starting line. Their first rocket was set on the sidewalk. They held a lighter under their match head and when I said "go" they all lit their lighters. We were using regular cigarette-type butane lighters. Because the flame had to stay lit for 8 seconds or so before ignition, many students were burning their thumbs. I ended up doing it for many of the students so burned my own thumb over and over.

For each heat the three rockets that went the farthest stayed on the ground where they landed. If they were beat out by rockets in a subsequent heat they were removed so that there were always only 3 rockets remaining on the ground by the time the next heat started. First, second and third place winners were all girls at 5'2", 4'6" and 3'5". They were excited. "The girls rule!"

There was not time to do the follow-up questions in the same class period as the contest, so those were done the next day. As students cleaned up at the end of the hour I overheard several students planning to make some more rockets at home. "I'm going to put five match heads in mine!"

APPENDIX IV J
FOLLOW-UP QUESTIONS ON HEAT ENGINES

How Does It Work?
Heat Engines

Gasoline Engine

Look at the diagram of a gasoline engine on p. 256 of your text.

1. What causes the crank shaft to turn so that the wheels on your car will turn?

2. What causes the piston to move down?

3. What heats the gas?

4. What is the hot reservoir in a gasoline engine?

5. What is the cold reservoir ?

6. Write an equation of the first law of thermodynamics that specifically describes the gasoline engine.

Rocket

Look at the tiny rockets you made.

1. What is the hot reservoir?

2. What is the cold reservoir?

3. What does the work of moving the rocket?

Teacher's Key
How Does It Work? Heat Engines

Gasoline Engine

Look at the diagram of a gasoline engine on p. 256 of your text.

1. What causes the crank shaft to turn so that the wheels on your car will turn?
   The piston moving up and down causes the crank shaft to turn.

2. What causes the piston to move down?
   The expansion of the heating gases causes the piston to move down.

3. What heats the gas?
   A spark from the spark plug heats the gas.

4. What is the hot reservoir in a gasoline engine?
   The hot gas in the cylinder is the hot reservoir.

5. What is the cold reservoir?
   The exhaust coming out of the tail pipe is the cold reservoir.

6. Write an equation of the first law of thermodynamics that specifically describes the gasoline engine.

$$Q_{\text{hot gas in clyinder}} = W_{\text{piston does on crank}} + Q_{\text{exhaust}}$$

Rocket

Look at the tiny rockets you made.

1. What is the hot reservoir?
   Gases heated by the burning match head inside the foil make up the hot reservoir.
2. What is the cold reservoir?
   The exhaust gases coming out of the tail comprise the cold reservoir.

2. What does the work of moving the rocket?
   Collisions of the fast moving gas particles against the inside of the foil on the wall opposite the tail pipe. (There are no collisions in the tail pipe direction as there is no wall for the particles to hit against.)

ANECDOTAL COMMENTARY ON "HOW DOES IT WORK?"

Any diagram of a gasoline engine would work as the visual for the first set of questions. The only requirements would be that it showed the piston and the spark plug. Students had trouble figuring out what caused the piston to move down. When none of them came up with the answer, I guided them through with questions such as "What is in the cylinder?" "What happens to the gas when the spark ignites?" "How does a gas change as its temperature increases?" Students also had trouble figuring out what the cold reservoir was. I finally just told them that it was the gas outside of the car.

After answering the questions on the car engine, students had no trouble identifying the hot and cold reservoirs on their tiny rockets. Number three however, had them stumped. There was an excellent explanation in a packet available on the internet titled Chapter 5 Thermodynamics. (http://sci-toys.com/scitoys/scitoys/thermo/therm.html). The explanation is in the top three paragraphs on page 7. I read it aloud to them after they took a few stabs on their own at possible answers.

APPENDIX IV K
DESIGN YOUR OWN SOLAR COLLECTOR EXPERIMENT

STUDENT COPY

Purpose: To engage in authentic research that will contribute toward improvements in solar collector design, and to communicate the findings to the scientific and alternative energy communities via internet postings.

Background: Draw two labeled diagrams of a flat plate solar collector (one top view, one side view).

Developing Your Research Question:

1. Looking at the drawing you made, and thinking about the functions of the various components, make a list of things that could be varied and tested.

CLASS DISCUSSION AFTER THIS STEP! To pool our ideas.

2. During the class discussion of possible components to vary, choose which component you would like to experiment with and get the teacher's approval (so that we are not all investigating the same one).

   In my experiment I plan to investigate the effects of varying ___________________

   ____ .

3. Brainstorm possible methods for investigating variation in the chosen parameter. Draw diagrams and jot notes on separate pages that you label "Brainstorming". Attach those papers to this packet. Think about the physical set-up, taking care that only ONE parameter is varied, that the procedure really tests your research question, that you have a method to collect empirical data. Consider whether the materials you would need are available at school, at home, or are <u>really</u> cheap for you to purchase. Check with your teacher and your parents. We may be able to help you think of cheap or common sources for your materials.

4. Discuss your ideas with other students to get help overcoming obstacles and to refine your plan.

5. Fill out the attached form titled "Research Proposal".

6. Meet with your teacher to get approval. Be prepared to discuss everything on your proposal sheet.

7. Perform the experiment. Record data in ink. Put dates and times on pages. Take digital photos of your set-ups and as part of data collection if applicable.

8. Write a formal lab report. See handout titled "Format for Lab Write-Ups".

9. Present your report to the class. We will discuss it.

10. Post your findings on our web page.

Research Proposal

Researcher's Name: ________________________________ Date of meeting: ______

Parameter Under Study: ____

(The component you will study. Example: box depth)

Variations of Parameter:

(Example: box depths of 6 cm, 12 cm, 18 cm)

____

____

____

Control: ____

(Example: 2 boxes of the same depth to see what sort of natural variation is inherent in your system)

Diagram: Draw and label your planned experimental set-up.

Procedure: Describe it to me verbally. Then we will discuss the following questions, which you will already have written answers to below.

1. Is there really only one variable?

2. Does your procedure really test what you want it to test?

3. Is it logistically possible? (time-wise, location-wise?)

4. List the empirical data you will be able to gather:

5. What will be possible sources of error and how could you minimize them?

6. What assumptions have shaped your choice of variations in the parameter?

Materials Needed: (list them) We will discuss where you can get each one.

points: _____

Instructor's Approval ____ date ______

Teacher's Key
Design Your Own Solar Collector Experiment

Purpose: To engage in authentic research that will contribute toward improvements in solar collector design, and to communicate the findings to the scientific and alternative energy communities via internet postings.

Background: Draw two labeled diagrams of a flat plate solar collector (one top view, one side view).

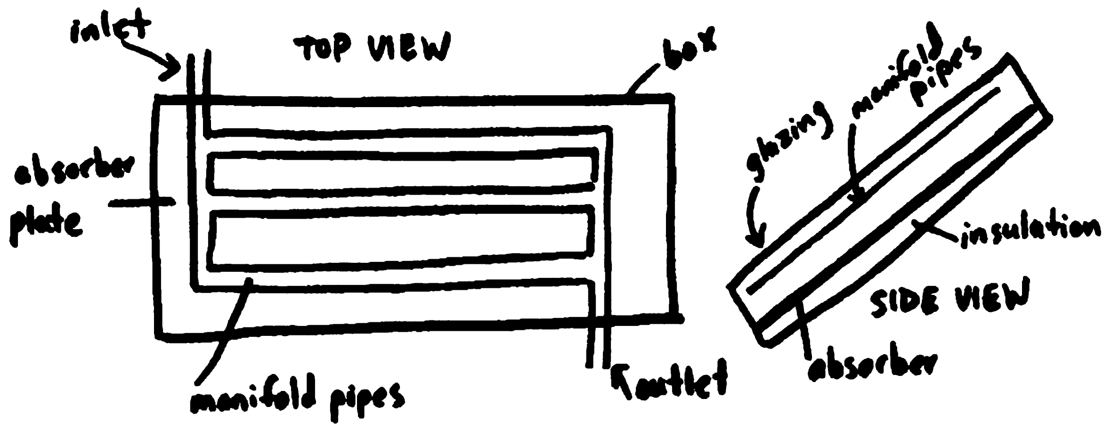


Figure 90 Flat Plate Collector (teacher's drawing)

Developing Your Research Question:

1. Looking at the drawing you made, and thinking about the functions of the various components, make a list of things that could be varied and tested.

Identity of liquid in manifold
Material manifold is made of (types of metal, plastic, rubber, glass)
Color or other optical properties of manifold material (transparent, opaque)
Diameter of manifold tubes or thickness of the tubing walls
Amount of tubing
Distance manifold is from the absorber
Size and shape of the box
Absorber material, color, thickness, mass
Material used for glazing, thickness, alterations to make it transparent or opaque to certain frequencies
Insulation material, identity, thickness, placement
Orientation of collector with respect to the sun

CLASS DISCUSSION AFTER THIS STEP! To pool our ideas.

LAB FORMAT FOR EXPERIMENTAL WRITE-UPS
USED WITH DESIGN YOUR OWN SOLAR COLLECTOR EXPERIMENT

The following is a handout I give out to students at the beginning of the year. It shows the format that they are expected to follow for all lab reports for the year.

Lab Format for Experimental Write-Ups

Title: This should be descriptive and concise. It should mention the general type of system and any variable or relationship under study.
Example: The Effect of Nitrogen on Corn

Purpose: State why you are doing the experiment. If there is a hypothesis, it should be included here.
Example: The purpose of this experiment is to test the hypothesis that nitrogen causes corn plants to grow taller that they would otherwise grow.

Materials: This should be displayed as a list, rather than in paragraph form. Be specific so that others could replicate your experiment using the same materials.
Example: 75 corn seedlings in a garden of sandy loam soil
Miracle Gro fertilizer
Ruler

Procedure: This should be displayed step-wise, rather than in paragraph form. Be specific enough that others could replicate your experiment. Include a control and limit your variables to one.
Example:
1. Choose 3 groups of 25 corn seedlings in a garden of sandy loam soil that are far enough from each other that water will not be shared between them.
2. Measure the height of each plant and record along with the date.
3. Water all sets of plants the same amount on the same days, using a sprinkling can to insure the amounts are equal.
4. Apply Miracle Gro to one set of 25 plants according to the directions on the package.
5. Measure the height of all plants daily for two months, recording any qualitative observations as well.

Data and Observations: This section should include quantitative data displayed in a chart, table or other graphic as well as sentences of qualitative observations.

Example: Plant Height Raw Data

date	plant height (cm) for group 1 (control)	plant height (cm) for group 2 (control)	plant height for group 3 (nitrogen)

Figure 91 Sample Data Table

Average Height: _________ __________ ___________
Percentage of Difference Calculations:

Observations: It should be noted that the ground in the vicinity of group 2 appears to be lower that the surrounding land. Water tends to accumulate there after a rain more so than in the areas of groups 1 and 3.

Analysis and Conclusion: The raw data should be summarized and redisplayed in a form that shows any patterns or relationships that may be present, such as using bar graphs, x-y graphs, pie charts, etc. There should be a statement that ties back to the purpose. The experimenter should point out flaws in the original procedure and any irregularities or unexpected conditions. Improvements in procedure should be listed as well as suggestions for follow-up studies.

Example: Average height gain in centimeters

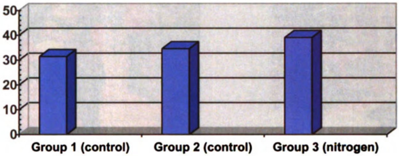


Figure 92 Sample Bar Graph

It appears that the nitrogen fertilizer Miracle Gro resulted in corn plants growing taller that they otherwise would have. The difference in height between the two controls could have been due to the lower elevation of the land in the area of group 2. Future follow-up studies should correct for that unwanted additional variable. Other follow-up studies should use nitrogen fertilizers other than Miracle Gro to be sure the difference in height was due to nitrogen and not some other constituent of that fertilizer.

PHOTOS OF DESIGN YOUR OWN SOLAR COLLECTOR EXPERIMENT

Figure 93a Cutting Foam for Insulation

Figure 93b Discussing Configurations for the Manifold

Figure 93c Encountering a Challenge That Led to Problem Solving

Figure 93d Filling the Manifold Tubing

Figure 93e Preparing Various Glazings

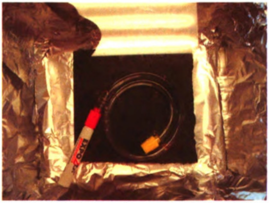


Figure 93f Creative Use of Materials

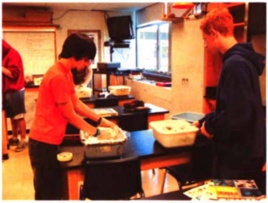


Figure 93g Preparing to Insulate

Figure 93h Outside and Ready to Collect data

Figure 93i Back inside, the data has been taken and it's time to take them apart and clean up

ANECDOTAL COMMENTARY ON DESIGN YOUR OWN SOLAR COLLECTOR

After drawing the flat plate collector, students wrote down everything they could think of that could be varied and tested. Then we discussed the list as a group, with students adding ideas of others to their own list. The exchange of ideas led to even more ideas.

Then students broke into groups and as a group, decided which parameter to vary. Many had trouble understanding, or figuring out, how to vary only one parameter. I overheard one student saying, "One will be black, one will have insulation and one will...." She was cut off by another group member who interrupted her, "No. Only one thing can be changed."

As in the Absorbance and Emission Lab, each group had three collectors. Two were identical to check for variation within the system. One was different in only one way.

When the groups moved on to #3, brainstorming their experimental design, there was an abundance of critical thinking and meaningful discussion. Most of the discussions revolved around what they would use for insulation. "How are we going to insulate the tubs?" "You have to have it exactly the same in all three tubs unless you are studying variations in insulation." "Will we just put it on the walls?" "No. And what about the top where the glass is?" "What are we going to use for the insulation?" One girl suggested using spray-on foam.

Another common discussion centered on the manifold. "Which tubing are we going to use?" "What is there the most of?" I had copper, clear plastic and black rubber tubing available in various diameters.

It took much longer that expected to meet with each group to discuss the research proposals. I had to go through every detail of their design with them, forcing them to make decisions about what they would use for their absorber, how they would close off the tubes of the manifold, how they would gather data and what data they would gather. I also had to help some groups narrow their variables down to just one. In the end, all groups chose a different parameter to vary. The spectrum included the material the manifold was made of, 3-D arrangement of the manifold, type of glazing, type of insulation and identity of the liquid in the manifold.

Most students still did not understand that the main function of the control was to see how much variation was inherent within design. The students did all seem to really enjoy having me go over every detail of the proposal with them. Their enjoyment of the creative aspect of designing the experiment from scratch was evident in their comments and the enthusiasm in which they went about planning it out.

Many seemed to relish the complexity of the details. One girl was thinking critically and focusing on detail when she asked, "Will it affect the outcome that the copper tube is stiff and will lay straight over the absorber, when the clear tubing is wimpy and sags down on either side?" We talked about the angle of the incoming radiation and differences in contact with the absorber versus having air space between the two. She ended up designing some supports (her idea totally) to put under both the copper and the clear tubing.

One boy was very excited about his design. He told me all about how his father had embedded pipes in the cement floor of their barn for hot water heat. The variable in this boy's experiment was the 3-D arrangement of the manifold. He said as his group was discussing the design he was envisioning the work his father had done laying out the pipe in the barn. To keep the groups busy while I was meeting with other groups, and to help review for the upcoming test, I had written a set of math problems on the board.

The day of the experiment all of the students were 100% fully engaged 100% of the time. They worked very efficiently and managed to get their collectors out into the sun before the end of the hour. One exception was a group of girls that always works very meticulously

Lots of problem solving occurred during construction. Students were running into design problems they had not anticipated and solving them as they went. They seem to absolutely love this sort of activity. I was rushing from one enthusiastic group to another helping them locate materials I don't normally have out. They were coming up with all sorts of creative ways to use materials to solve problems. "Can we get a funnel?" This group was having trouble filling their manifold tubes with antifreeze. "Do you have any wire?" This group's manifold was stiff and refusing to stay in the conformation they were trying to establish. One group came up with a creative way to stop the ends of their manifold tubes. They used caps from white board markers. They left the markers themselves attached so they wouldn't dry out.

Students were also discussing which data was important to gather. Some massed their brick absorbers. Some measured temperatures of the liquids before filling the manifold. Some wrote down the time they first set their collectors in the sun. I had all groups take photos of their set-ups after they got outside. Those could be used in their lab write-ups. Students took readings between classes and during their lunch.

The next day it was cloudy, so the group that hadn't finished in time to set their collectors outside put them under heat lamps. They were very careful to be sure each collector was receiving the same amount of radiation from the same angle at the same distance. They began working on the lab write-up as they took occasional data readings.

A couple of weeks previous, two students volunteered, for extra credit, to set up a way that all of the students could post their research results to the web. One student followed through, making it possible for the groups to share their scientific findings with the world. The day he finished figuring it out, the class all crowded around my computer to see what he had come up with. He walked the others through what they would need to do to post from their computer at home. The students were given a deadline of four days to post their full write-up from their computers at home. I then graded the write-up by accessing it on the web. I wrote down specific things that I wanted each group to change or improve in their posting and gave them a two-day deadline to do it. Then I read them over again and recorded their final grades.

APPENDIX V ELECTRICITY ACTIVITIES

APPENDIX V A
Building Circuits

In groups of 2, using materials of your choice from the cart, build:

Teacher's Signature

a) a circuit that will light a bulb ______________

b) a series circuit and a parallel circuit that both light a bulb ______________

c) a series circuit in which first you have one bulb, then you add a second bulb, and finally you add a third bulb. ______________

Did you see any difference in brightness when you added bulbs? ____________

d) a parallel circuit in which first you have one bulb, then you add a second bulb, and finally you add a third bulb. ____________

Did you see any difference in brightness when you added the bulbs? ____________

e) Design your own special circuit. Be creative and show off! ____________

Teacher's Key for Building Circuits

In groups of 2, using materials of your choice from the cart, build:

Teacher's Signature

a) a circuit that will light a bulb ______________

b) a series circuit and a parallel circuit that both light a bulb ______________

c) a series circuit in which first you have one bulb, then you add a second bulb, and finally you add a third bulb. ______________

Did you see any difference in brightness when you added bulbs? **Yes. The bulbs become less bright as more bulbs are added.**

d) a parallel circuit in which first you have one bulb, then you add a second bulb, and finally you add a third bulb. ______________

Did you see any difference in brightness when you added the bulbs? **No.**

e) Design your own special circuit. Be creative and show off! ______________

ANECDOTAL COMMENTARY ON BUILDING CIRCUITS ACTIVITY

A three-shelf cart was stocked with all kinds of electrical equipment including: coated wires, various sizes of bulbs (including enough miniature bulbs for each group to have at least four), bulb receptacles, switches, buzzers, mini motors, batteries of various sizes and voltages, circuit boards with accompanying boxes of wires, wire strippers, masking tape, and cables with alligator clip ends and/or banana lead ends. Note that it takes three volts to get good bright light out of 4 mini bulbs. And if students include too much wire in their circuit, the resistance of the wire can make the light too dim to see.

It's necessary to have extra miniature bulbs on hand. Students burn bulbs out during the course of the lab by dropping them and by passing too much current through them. We usually lose about the same number of bulbs as there are students in the class.

It's also important for the instructor to test the batteries and bulbs before the lab. Students may struggle and get frustrated thinking they just aren't smart enough to build a working circuit, when they may just have faulty equipment. Use a multi meter to test the batteries. Set is on V for voltage. AA and D batteries should read close to 1.5 volts.

Some of the students complained that they didn't have enough materials. They would see another group screwing a bulb into a receptacle and think they had to have receptacles too. I explained that the bulbs work without receptacles and stood nearby to continually encourage them at their attempts to get their bulbs to light. I finally showed a couple of girls where they needed to place the wires on their bulbs.

Some students thought they wouldn't be able to get their circuit to work without a switch and were angry that there weren't enough switches for everyone. I assured them that it would work without a switch and they went ahead and built a circuit. Introducing a switch later into their circuit helped them realize the true function, and why it is that you don't need one to have a complete circuit.

I designed this lab several years ago so this was not the first year to try it out. For the first year ever, there were no groups where one student did all of the tinkering while the other just watched. All students had their hands on the equipment. This lab took one and a half class periods to complete. I wanted to be sure that even the students who found this the most challenging, had time to finish.

I have puzzled over one outcome of this lab for several years. It would be a great question for students to do as a follow-up study. In a series circuit, the bulbs are supposed to get less bright as you add more bulbs. The bulbs in the parallel circuit are supposed to all exhibit the same amount of brightness regardless of whether there are one, two or three bulbs in the circuit. We often see just the opposite when we do this lab. I am wondering if the length of wire is the cause. Perhaps the introduction of extra wire for the parallel portions adds enough resistance to cause dimming in these small bulbs.

APPENDIX V B

Electrolysis Lab

Purpose: To build a system in which electrolysis can be observed.

Materials:

9-Volt alkaline battery
1.5 volt alkaline battery
Ring stand
Clamp
Coated copper wire
Wire cutter/stripper
Large paper clip
18 cm of ¼" clear flexible plastic tubing
Small beaker
Table salt (NaCl)
Masking tape
Distilled water

Background:

A battery has _________ poles. Electrolysis happens when the two terminals of a battery are bathed in a solution containing an ____________________ . Anions are attracted to the ___________ because it has a ______________ charge. Cations are attracted to the _______________ because it has a ________________ charge. In this lab we will use ___________ for the electrolyte. The portion of the system where electrolysis takes place is called the _________________________________ .

Procedure:

1. Look the batteries over and draw them below. Label the anode and the cathode and their charges.

2. Attach the clamp to the ring stand. Secure the 9-volt battery in the clamp. (See figure 3)
3. Cut 2 wires that are about 20 cm long. Strip the plastic from both ends of each wire.
4. Wrap the end of one wire securely around the anode of the 9-volt battery and one end of the second wire around the cathode. Cover those ends with a piece of masking tape to hold them in place.
5. Put the ends of the clear tubing through the opposite end of the paper clip bending the tubing into a U shape. (See figures 1 and 2) This is the electrolytic cell.
6. Fill the tubing with distilled water. Eliminate any air bubbles.
7. Stick the anode wire into one end of the U tube and the cathode wire into the other end.

8. Observe both wires for 2 minutes and record observations in the data section.
9. While waiting the 2 minutes in step 8 above, put about 25 ml of distilled water into the beaker. Add about ½ tsp salt. Swirl to dissolve as much salt as possible.
10. Repeat step 6 using the salt water in place of distilled water.
11. Observe both wires for 5 minutes recording observations in the data section.
12. While waiting the 5 minutes in step 11 above, draw the experimental set-up below, labeling the battery, cathode, anode, electrolytic cell, electrolytic solution, hydrogen gas, chlorine gas, and electric current.

Data:

	Observed at Anode	Observed at Cathode
No Salt in the Cell:		
Other observations:		
NaCl in the Cell:		
Other observations		

Theory:

1. What is the composition of the gas bubbles at the anode?
   Write the reactions that led to the production of this substance.

2. What would be the composition of the gas bubbles you expected to see at the cathode?
   Write the reactions that led to the production of this substance.

3. Why aren't we seeing bubbles at the cathode? (Take a guess.)

4. Does electrolysis produce electric current, or do you need to supply electric current for electrolysis to happen?

5. Where did the current come from?

6. What would happen if you replaced the electrolytic cell with a bulb?

7. What would happen if you replace the battery with a bulb? (try it)

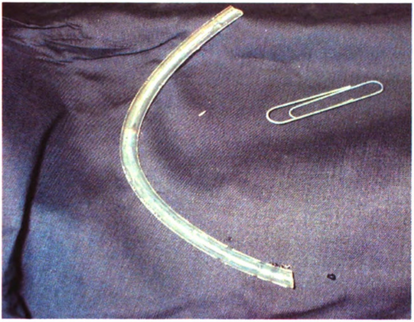


Figure 94 Materials Needed to Construct U-Tube (Figure 1 on Student's Copy)

Figure 95 The U-Tube (Figure 2 on Student's Copy)

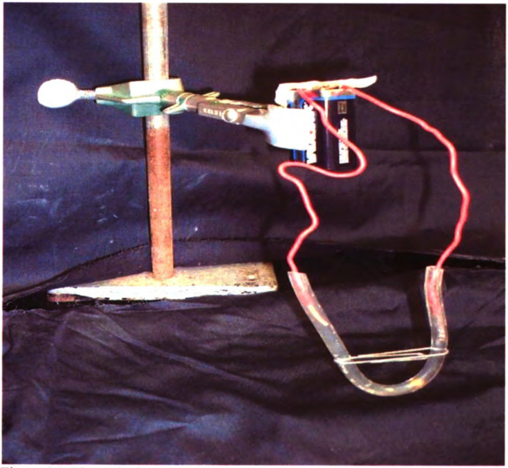


Figure 96 Electrolysis Apparatus (Figure 3 on Student's Copy)

Electrolysis Lab

Purpose: To build a system in which electrolysis can be observed.

Materials:

- 9-Volt alkaline battery
- 1.5 volt alkaline battery
- Ring stand
- Clamp
- Coated copper wire
- Wire cutter/stripper
- Large paper clip
- 18 cm of ¼" clear flexible plastic tubing
- Small beaker
- Table salt (NaCl)
- Masking tape
- Distilled water

Background:

A battery has **two** poles. Electrolysis happens when the two terminals of a battery are bathed in a solution containing an **electrolyte**. Anions are attracted to the **cathode** because it has a **positive** charge. Cations are attracted to the **anode** because it has a **negative** charge. In this lab we will use **NaCl** for the electrolyte. The portion of the system where electrolysis takes place is called the **electrolytic cell**.

Procedure:

1. Look the batteries over and draw them below. Label the anode and the cathode and their charges.

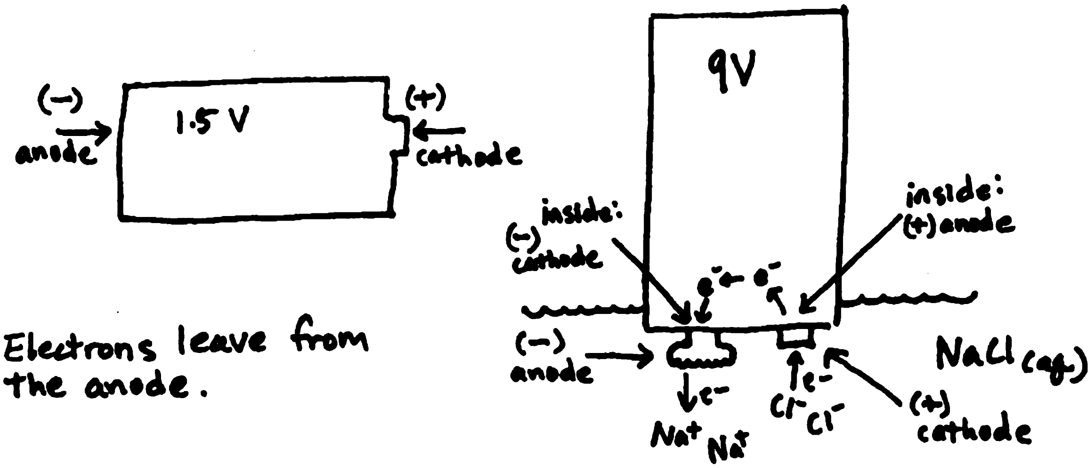


Figure 97 Labeled Drawing of Batteries (teacher's drawing)

2. Attach the clamp to the ring stand. Secure the 9-volt battery in the clamp. (See figure 3)
3. Cut 2 wires that are about 20 cm long. Strip the plastic from both ends of each wire.

4. Wrap the end of one wire securely around the anode of the 9-volt battery and one end of the second wire around the cathode. Cover those ends with a piece of masking tape to hold them in place.
5. Put the ends of the clear tubing through the opposite end of the paper clip bending the tubing into a U shape. (See figures 1 and 2) This is the electrolytic cell.
6. Fill the tubing with distilled water. Eliminate any air bubbles.
7. Stick the anode wire into one end of the U tube and the cathode wire into the other end.
8. Observe both wires for 2 minutes and record observations in the data section.
9. While waiting the 2 minutes in step 8 above, put about 25 ml of distilled water into the beaker. Add about ½ tsp salt. Swirl to dissolve as much salt as possible.
10. Repeat step 6 using the salt water in place of distilled water.
11. Observe both wires for 5 minutes recording observations in the data section.
12. While waiting the 5 minutes in step 11 above, draw the experimental set-up below, labeling the battery, cathode, anode, electrolytic cell, electrolytic solution, hydrogen gas, chlorine gas, and electric current.

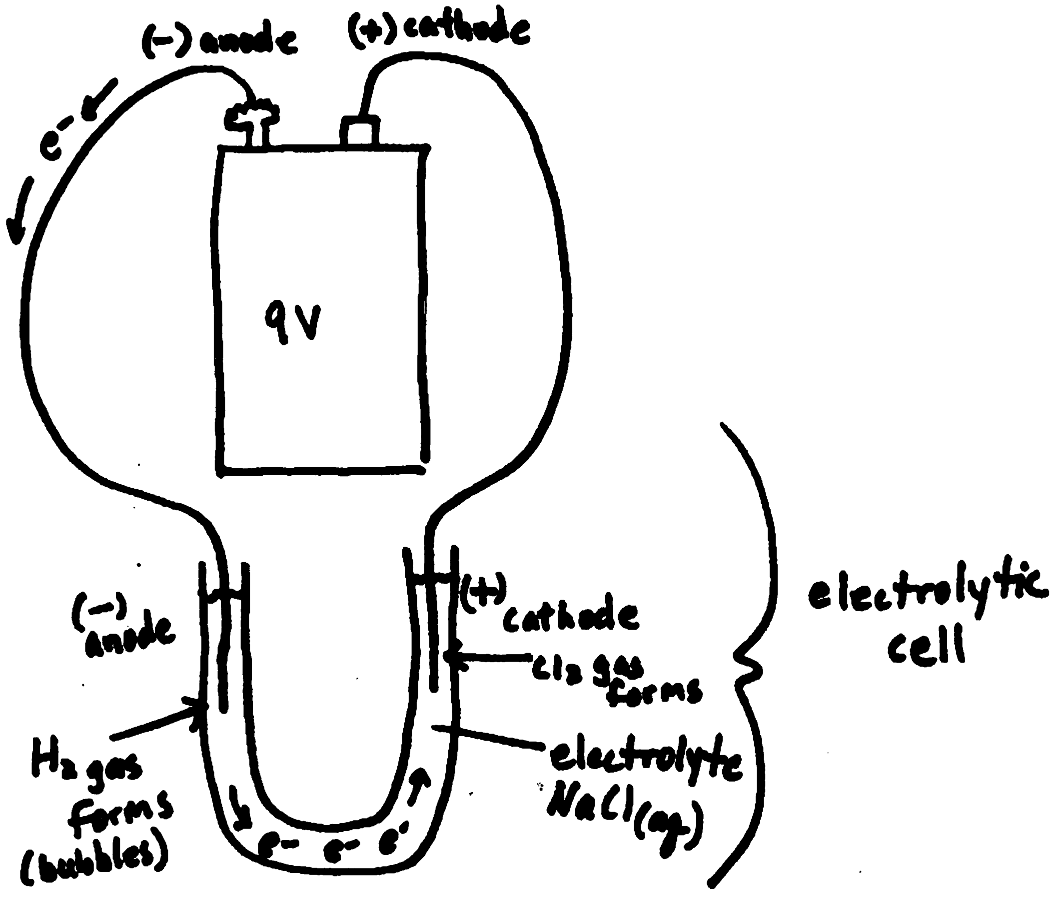


Figure 98 Labeled Drawing of Experimental Set-Up (teacher's drawing)

Data:

	Observed at Anode	Observed at Cathode
No Salt in the Cell:	**tiny bubbles after 2 minutes right on the wire**	**tiny bubbles after 2 minutes right on the wire**

Other observations:

NaCl in the Cell:	**lots of bubbles coating the wire. Lots of small bubbles being produced at the wire and rising to the top of the solution.**	**A few bubbles on the wire. Can't see them being produced. None rise.**

Other observations: **If the anode and cathode are accidentally mixed up on a second trial, a yellow/brown substance is produced in large quantities.**

Theory:

1. What is the composition of the gas bubbles at the anode? **H_2 gas**
   Write the reactions that led to the production of this substance.

$$\left.\begin{array}{l} \mathbf{Na^+ + e^- \rightarrow Na} \\ \mathbf{Na^+ + e^- \rightarrow Na} \\ \mathbf{HOH \rightarrow H + OH} \\ \mathbf{HOH \rightarrow H + OH} \end{array}\right\} \rightarrow \mathbf{2NaOH + H_2}$$

2. What would be the composition of the gas bubbles you expected to see at the cathode? **Cl_2**
   Write the reactions that led to the production of this substance.

$$\left.\begin{array}{l} \mathbf{Cl^- \rightarrow e^- + Cl} \\ \mathbf{Cl^- \rightarrow e^- + Cl} \end{array}\right\} \rightarrow \mathbf{Cl_2 + 2e^-}$$

3. Why aren't we seeing bubbles at the cathode? (Take a guess.)
   Probably because chlorine gas is very soluble in water so it dissolves right away. If it builds to a high enough concentration, the water could turn slightly yellow and could bleach litmus white. We did not observe this.

4. Does electrolysis produce electric current, or do you need to supply electric current for electrolysis to happen?
   You have to supply electric current to get the non-spontaneous process of electrolysis to happen.

5. Where did the current come from? **From chemical reactions in the battery.**

6. What would happen if you replaced the electrolytic cell with a bulb?
   Current would flow so the bulb would light up.

7. What would happen if you replace the battery with a bulb? (try it)
   No current flows so the bulb does not light.

ANECDOTAL COMMENTARY ON THE ELECTROLYSIS LAB

We began the lesson with the students thinking of different ways that electricity can be made. Several students mentioned that generators change mechanical energy to electrical energy. With prodding, students named wind turbines and water turbines as types of generators. I asked, "What device operates backwards of a generator?" No one knew that a motor changes electrical energy to mechanical. Most students did know that a battery changes chemical energy to electrical, but did not know that electrolysis was the opposite transformation. And since electrolysis was the topic of this lab, the students were learning something totally new.

None of the students knew the term for the device that transforms light energy to electrical energy: photovoltaic cell. The only term they were familiar with was solar power.

As usual, students really enjoyed the hands-on aspect of the lab and were very focused and absorbed. As I looked around the room after the students had their equipment set up, I saw a class full of noses inches from the U-tubes with eyes fixated upon the wire terminals.

Some students did have trouble eliminating bubbles from their U-tubes as they attempted to fill them with distilled water or electrolyte. Delivering a quick, firm flick of the finger to the U-tube a time or two seems the best way to get rid of the trapped air. Some students also had luck holding the tube at a 45 degree angle when filling.

No one noticed the tiny bubbles on both electrodes when the U-tube contained only distilled water. Perhaps it would be a good idea to supply magnifying glasses so that the students realize that we may be looking for bubbles that are really tiny.

The bubbles produced when using the NaCl electrolyte are easily observed. Unfortunately, four out of the five groups had to really rush to see the results with electrolyte. Consequently, they were unable to see if their concentrations of Cl_2 became high enough to turn the water yellow or bleach litmus paper. There was also no time to try switching the electrodes and hypothesizing about the identity of the yellow/brown substance that would have been produced.

APPENDIX V C
CAR BATTERY DEMONSTRATION

Teacher Instructions for the Car Battery Demo
Testing Specific Gravity and Voltage

Equipment to Gather

Spare car battery (for lifting)
Battery in car (NOT maintenance-free. You need to be able to pry caps off cells.)
Hygrometer (made especially for testing car batteries)
Voltmeter
Screw driver for removing caps
Safety goggles for all
Student question sheets
Clipboards for all (optional)
Kleenex (and baking soda, water and toothbrush if lots of corrosion)

Prep Work

1. Borrow hygrometer.
2. Load spare battery into car.
3. Drive car to school so battery is fully charged.

Actual Demonstration

1. Distribute goggles, question sheet and clipboard to each student.
2. Class walks to location of teacher's car in parking lot.
3. Teacher immediately turns headlights on (high beam). They need to be left on for 6 minutes to get rid of any dangerous surface charge.
4. Students try lifting the spare battery.
5. Students fill in question 1 and do drawings under numbers 2 and 3.
6. Safety Talk:
    - eye protection
    - remove surface charge
    - take jewelry off

    Reasons:
    - the hydrogen gas generated from the sulfuric acid is explosive
    - the electrolyte (aqueous sulfuric acid) is 35% H_2SO_4, so if the battery blows up you get showered with H_2SO_4.
    - 100 amps of current run through the car's electric system
7. Students fill in 4a,b,5,6 on question sheet.
8. Seven student volunteers take off jewelry and put in their pocket or give to a friend.
9. One volunteer use the meter to take the voltage reading. If it is a multimeter, turn the dial to DCV, 20. The student places the red electrode against the positive (red) post on the battery and the black electrode against the negative (ground, black) post. (See photos 1 and 2).
10. Students fill in question 7.

11. Clean off battery top with a Kleenex so no dirt, etc will fall into the cells when the caps are removed. If there is a lot of corrosion it can be cleaned off with baking soda, water and a tooth brush.
12. Pry the tops off the cells with a screwdriver. (See photos 3 and 4).
13. Six volunteers each use the hygrometer to measure the specific gravity of one of the six cells. It operates like a turkey baster. Insert into the cell with bulb end up. Suck up the electrolyte by squeezing the bulb and then releasing. Liquid will come up into the neck of the baster. They hygrometer inside will float in that fluid. (See photos 5 and 6).
14. Students fill in number 8 on question sheet. See table on last page for info.
15. Discussion: How would the batteries in electric hybrids be different than this battery? How would they be similar? Students write their ideas under numbers 10 and 11 on answer sheet.
16. Everyone put their jewelry back on.


(Photo 1 on original document)

Figure 99 Testing Voltage on a Car Battery


(Photo 2 on original document)

Figure 100 Close-Up of Testing Voltage on a Car Battery


(Photo 3 on original document)

Figure 101 Prying Caps Off the Battery Cells


(Photo 4 on original document)

Figure 102 The Battery Cells Are Now Accessible

Figure 103 Squeeze the Bulb and Insert the Hygrometer (Photo 5 on original document)

Figure 104 Reading Specific Gravity Value (Photo 6 on original document)

Percent Charge Vs. Specific Gravity and Voltage

% Charged	Specific Gravity	Voltage
100 %	1.265	12.7 V
75%	1.225	12.4 V
50%	1.190	12.2 V
25%	1.155	12.0 V
Discharged	1.120	11.9 V

Car Battery Demo Questions

1. Why are car batteries so heavy?

2. Make a labeled drawing of a whole car battery.

3. Make a labeled drawing of a single cell in a car battery.

4. a) Write the reaction for H_2SO_4 dissolving in water.

   b) What is dangerous about this process?

5. Write the reaction that takes place at the anode (+) while the headlights are on (which means the battery is discharging).

6. At which terminal are the electrons that make up the electric current produced?

7. Voltage reading ________________
According to the voltage reading the battery is _________ % charged.

Percent Charge Vs. Specific Gravity and Voltage

% Charged	Specific Gravity	Voltage
100 %	1.265	12.7 V
75%	1.225	12.4 V
50%	1.190	12.2 V
25%	1.155	12.0 V
Discharged	1.120	11.9 V

8. Specific gravity readings:

Cell	Reading	% Charged
1		
2		
3		
4		
5		
6		

9. a) Too little H_2SO_4 would give a high/low specific gravity reading.
b) Too little H_2SO_4 results in fewer/more electrons produced.
c) Amount of H_2SO_4 in our battery is high/low/just right.
d) Specific gravity readings should not vary by more than 0.05 between cells.
By how much did our readings vary? ______________

10. How would the battery in an electric hybrid be different than this battery?

11. How would the battery in a hybrid be similar to this lead-acid batter?

Teacher's Key to the Car Battery Demo Questions

1. Why are car batteries so heavy?

   They contain many plates made of lead and lead oxide.

2. Make a labeled drawing of a whole car battery.

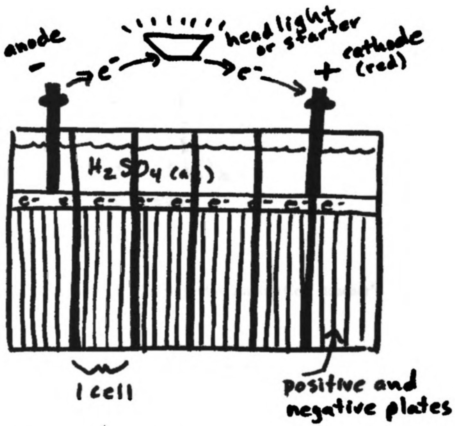


Figure 105 Labeled Drawing of a Car Battery (teacher's drawing)

3. Make a labeled drawing of a single cell in a car battery.

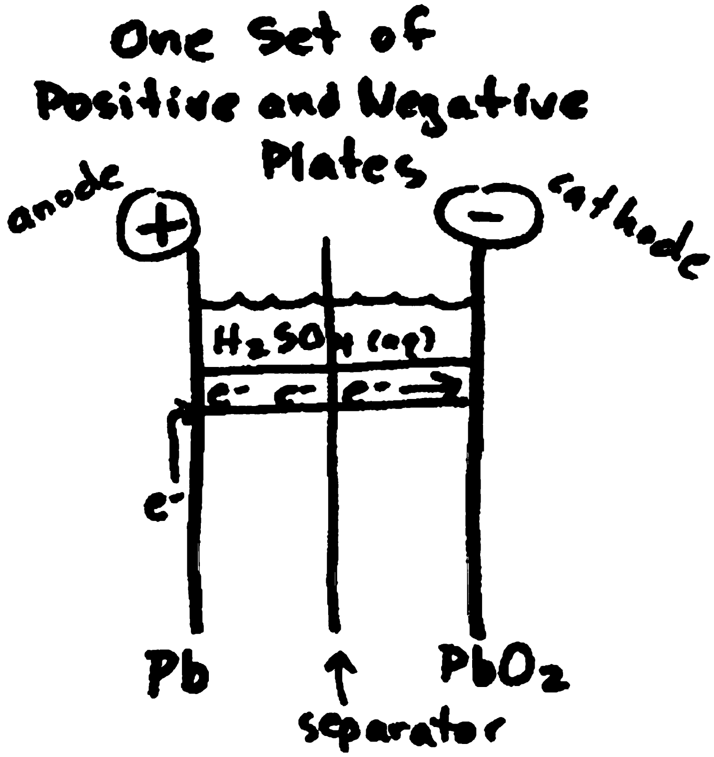


Figure 106 Labeled Drawing of a Single Car Battery Cell (teacher's drawing)

4. a) Write the reaction for H_2SO_4 dissolving in water.

$$H_2SO_{4\,(aq)} \rightarrow 2H^+_{(aq)} + SO_4^{2-}{}_{(aq)}$$

b) What is dangerous about this process?

Some H^+ combines with electrons to make H_2 gas which is explosive.

6. Write the reaction that takes place at the anode (+) while the headlights are on (which means the battery is discharging).

$$\mathbf{Pb + \;+ SO_4^{2-} \rightarrow PbSO_4 + 2e^-}$$

The SO_4 is oxidized: -2 charge → 0 charge

7. At which terminal are the electrons that make up the electric current produced?
The anode.

8. Voltage reading <u>**12.66 V**</u>
According to the voltage reading the battery is <u>**almost 100**</u> % charged.
*****Values shown here are from my own battery. They can be used if your class does not have access to a real car battery.**

Percent Charge Vs. Specific Gravity and Voltage

% Charged	Specific Gravity	Voltage
100 %	1.265	12.7 V
75%	1.225	12.4 V
50%	1.190	12.2 V
25%	1.155	12.0 V
Discharged	1.120	11.9 V

9. Specific gravity readings:***

Cell	Reading	% Charged
1	**1.263**	**almost 100**
2	**1.262**	**almost 100**
3	**1.214**	**almost 70**
4	**1.262**	**almost 100**
5	**1.263**	**almost 100**
6	**1.263**	**almost 100**

*****This data came from my own car battery**

10. a) Too little H_2SO_4 would give a high/low specific gravity reading.
b) Too little H_2SO_4 results in fewer/more electrons produced.
c) Amount of H_2SO_4 in our battery is high/low/just right.
d) Specific gravity readings should not vary by more than 0.05 between cells. By how much did our readings vary? <u>**.001 for most, .049 for one*****</u>

10. How would the battery in an electric hybrid be different than this battery?
    1. **It needs to store a lot more charge for its size. (It has to move the heavy car down the road and power the accessories like headlights, starter and air conditioner.**
    2. **It can be recharged via braking or by plugging into the wall as well as from energy generated by the engine.**
    3. **The voltage is higher.**

11. How would the battery in a hybrid be similar to this lead-acid battery?
Both types get charged as the car drives down the road (by energy generated by the gas engine).

ANECDOTAL COMMENTARY ON THE CAR BATTERY DEMO

My car was hit by a deer just prior to this and couldn't be driven. So I had to use the car battery that we had in class. It is a demonstration model with part of the outer case cut away so that the innards can be viewed. It contains no electrolyte of course, and so is not functional.

I used the digital projector to display the photos of me actually testing the real battery in my car. Students used the data I had collected from my battery when the photos were taken. This allowed them to complete the rest of the questions. I have included that data in the teacher's key in case there is not a working battery available for others who would like to do this exercise.

Most students were very interested and answered many questions that I threw out to them. "Which acid is the acid in a lead-acid battery?" They shouted out guesses without worrying about being wrong.

Some students were interested and followed along so closely that when I wrote the half-reactions of hybrid car batteries on the board afterwards, they caught a mistake I made. One of them reactions wasn't balanced. Several students were excited enough that they planned to check their own car's battery to see if it is the types whose caps can be removed.

APPENDIX V D

Galvanic Battery Lab
The Voltaic Pile

Adapted from the commonly known lab by the same name.

Purpose: To build a simple galvanic battery and measure voltages produced when parameters are varied.

Materials:

5 pennies	Multimeter (or volt meter)
5 nickels	Table salt
Paper towels	100-ml graduated cylinder
Distilled water	10- or 25-ml graduated cylinder
Stirring rod	600-ml beaker
9-Volt battery	

Procedure:

1. Dissolve 6 ml of table salt in 100 ml of distilled water in the 600-ml beaker. Stir to help it dissolve.
2. Fold a paper towel up so that it fits into the bottom of the 600-ml beaker. It should be at least 4 layers thick after folding.
3. Soak the towel in the salt water for at least 5 minutes. Answer pre-lab questions on the back while waiting.
4. Tear 5 pieces (full 4-layer thicknesses) off the soaked paper towel. The size of each piece should be a little smaller than the diameter of a penny.
5. Build 5 separate cells, each consisting of a nickel and a penny with the piece of layered torn paper towel between. (See photo.)

Figure 107 Five Galvanic Cells

6. Using the multi meter (with the dial set at DCV 2000m) measure the potential difference (voltage) on each cell. Do it by placing one of the meter leads on the penny and the other on the nickel. Record readings below.

________ ________ ________ ________ ________ ________

7. What happens when you switch which lead you are putting on which coin?

8. Thinking of when you put the meter's leads on the terminals of the 9-volt battery to get a positive reading (red was on the positive terminal and black was on the negative one) which coin is the
   Positive terminal? ____________________
   Negative terminal? ____________________

9. In conventional current, electricians think of electricity as positive charges flowing out of the positive terminal going toward the ________________ terminal. We know that electrons are negative and that flowing electrons are what electric current is. So as physicists, we think of current as electrons flowing out of the negative terminal and into the ________________ terminal. (And it makes sense that a negative electron would be attracted to a positive terminal.) Keeping all of this in mind, which coin are electrons flowing out of? ________________

10. Label which coin is the nickel and which is the penny on pre-lab question 3

11. Put the 5 cells in a stack one on top of the other, being sure the same coin type is on the bottom half of each cell. Check the voltage by placing one lead on the bottom coin of the pile and the other lead on the very top coin of the pile.
    Voltage of voltaic pile: ____________________
    Looking at this voltage (compared to voltages of the individual cells) and the way the cells are arranged, would you say that the cells are in series or parallel? Explain.

12. Create a parallel circuit by placing the individual cells on a triple thickness of paper towel that has been soaked in salt water. (See photo.)

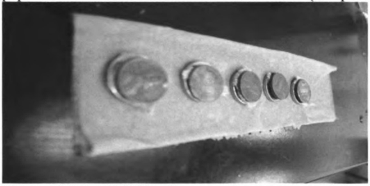


Figure 108 Parallel Circuit

13. Now the electrons have more than one possible path to follow. Use the multimeter to measure potential differences at various points in the circuit. Do any of the measurements match the reading for the series circuit? Explain why or why not.

Pre-Lab Questions:

1. Turn the dial on the multi meter to DCV 20. Put the leads on the terminals (poles) of the 9-Volt battery. You can only get a positive reading when the _____________ lead is on the _______________ terminal and the _________________ lead is on the ___________________ terminal.

2. Draw a labeled diagram of the cell you will be building out of a nickel a penny and a piece of paper towel soaked in salt water. Label the electrolyte also.

3. We will touch one electrode to the coin on top and the other electrode to the coin on the bottom. When we do this the coin cell will be discharging. Electrons will flow from one coin into the meter, through the meter, into the other coin, through the electrolyte in the paper towel and back to the original coin. But right now we don't know which coin is the anode and which is the cathode.

   While discharging,

   The ____________ is the terminal electrons from which electron flow out of the battery and the _______________ is the terminal from which the electrons will flow into the battery. (Fill in the blanks with anode or cathode.)

   Draw the coin cell again below with the meter hooked up to it. Show electron flow using arrows. Do not label which coin is the nickel or penny yet, as we yet know which one the electrons will be flowing out of.

Post Lab Questions and Activities:

1. What could be possible reasons for the 5 individual cells having different voltages?

2. Think of something that you could change in the procedure or setup. Describe your change below, test the consequences of the change with the meter and record below. Write a possible explanation for the results obtained.

3. What kinds of things would you alter and test if you were trying to engineer a battery that produced high enough voltages to power a hybrid or plug-in car?

4. The $500 question is......Why DO electrons flow when you connect a meter to a penny and a nickel (or any dissimilar metals) that are separated by an electrolyte?

Galvanic Battery Lab Teacher's Key
The Voltaic Pile

Adapted from the commonly known lab of the same name.

Purpose: To build a simple galvanic battery and measure voltages produced when parameters are varied.

Materials:

5 pennies	Multimeter (or volt meter)
5 nickels	Table salt
Paper towels	100-ml graduated cylinder
Distilled water	10- or 25-ml graduated cylinder
Stirring rod	600-ml beaker
9-Volt battery	

Procedure:

1. Dissolve 6 ml of table salt in 100 ml of distilled water in the 600-ml beaker. Stir to help it dissolve.
2. Fold a paper towel up so that it fits into the bottom of the 600-ml beaker. It should be at least 4 layers thick after folding.
3. Soak the towel in the salt water for at least 5 minutes. Answer pre-lab questions on the back while waiting.
4. Tear 5 pieces (full 4-layer thicknesses) off the soaked paper towel. The size of each piece should be a little smaller than the diameter of a penny.
5. Build 5 separate cells, each consisting of a nickel and a penny with the piece of layered torn paper towel between. (See photo.)

Figure 109 Five Galvanic Cells

6. Using the multi meter (with the dial set at DCV 2000m) measure the potential difference (voltage) on each cell. Do it by placing one of the meter leads on the penny and the other on the nickel. Record readings below.

Possible data: 544 154 67 269 04 ← an oxidized penny

7. What happens when you switch which lead you are putting on which coin?
   The sign of the voltage reading changes

8. Thinking of when you put the meter's leads on the terminals of the 9-volt battery to get a positive reading (red was on the positive terminal and black was on the negative one) which coin is the
   Positive terminal? ___**the nickel**___
   Negative terminal? ___**the penny**___

9. In conventional current, electricians think of electricity as positive charges flowing out of the positive terminal going toward the ___**negative**___ terminal. We know that electrons are negative and that flowing electrons are what electric current is. So as physicists, we think of current as electrons flowing out of the negative terminal and into the ___**positive**___ terminal. (And it makes sense that a negative electron would be attracted to a positive terminal.) Keeping all of this in mind, which coin are electrons flowing out of? ___**the penny**___
   $\mathbf{Cu \rightarrow Cu^{2+} + 2e^-}$

10. Label which coin is the nickel and which is the penny on pre-lab question 3

11. Put the 5 cells in a stack one on top of the other, being sure the same coin type is on the bottom half of each cell. Check the voltage by placing one lead on the bottom coin of the pile and the other lead on the very top coin of the pile.
    Voltage of voltaic pile: ___**903V (a possible reading)**___
    Looking at this voltage (compared to voltages of the individual cells) and the way the cells are arranged, would you say that the cells are in series or parallel? Explain. **The cells are arranged in series. The voltages appear to be adding together.**

12. Create a parallel circuit by placing the individual cells on a triple thickness of paper towel that has been soaked in salt water. (See photo.)

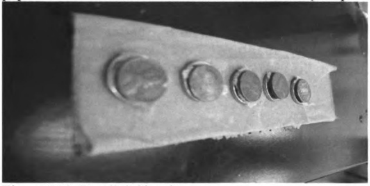


Figure 110 Parallel Circuit

13. Now the electrons have more than one possible path to follow. Use the multi meter to measure potential differences at various points in the circuit. Do any of the measurements match the reading for the series circuit? Explain why or why not. **No. In the series circuit voltages seemed to be adding together, and the electrons would have to flow through one cell to get to the next. There was**

only one path, so there were more and more electrons as you got to the end of the pile.

Pre-Lab Questions:

1. Turn the dial on the multi meter to DCV 20. Put the leads on the terminals (poles) of the 9-Volt battery. You can only get a positive reading when the ____**red**____ lead is on the ___**positive**_____ terminal and the ____**black**_____ lead is on the _____**negative**_____ terminal.

2. Draw a labeled diagram of the cell you will be building out of a nickel a penny and a piece of paper towel soaked in salt water. Label the electrolyte also.

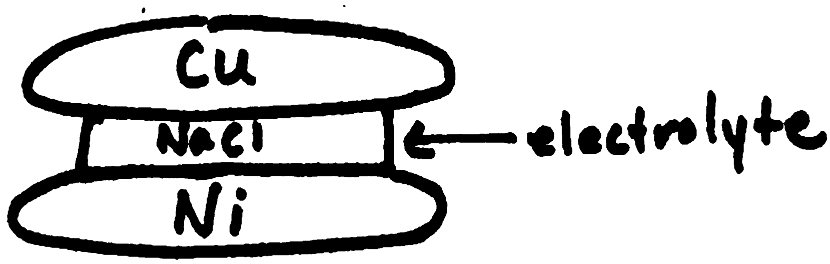


Figure 111 Labeled Drawing of One Cell (teacher's drawing)

3. We will touch one electrode to the coin on top and the other electrode to the coin on the bottom. When we do this the coin cell will be discharging. Electrons will flow from one coin into the meter, through the meter, into the other coin, through the electrolyte in the paper towel and back to the original coin. But right now we don't know which coin is the anode and which is the cathode.
4.

While discharging,
The ___**anode**__ is the terminal from which electrons flow out of the battery and the ____**cathode**___ is the terminal through which the electrons will flow into the battery. (Fill in the blanks with anode or cathode.)

Draw the coin cell again below with the meter hooked up to it. Show electron flow using arrows. Do not label which coin is the nickel or penny yet, as we yet know which one the electrons will be flowing out of.

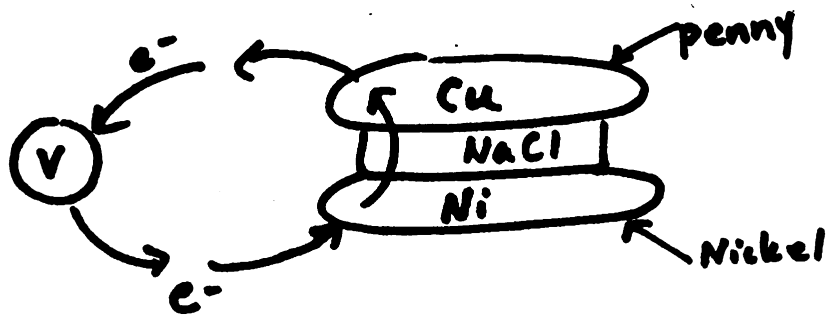


Figure 112 A Single Cell and a Multi Meter (teacher's drawing)

<u>Post Lab Questions and Activities:</u>

1. What could be possible reasons for the 5 individual cells having different voltages?
   Bigger or smaller differences in charge between the nickel and penny due to:
   - outer layer oxidized (so mobile electrons are not near the surface)
   - more or less metal making contact with the electrolyte (due to size and shape of the paper towel)
   - differing concentrations of electrolyte
   - different amounts of saturation of the paper towel

2. Think of something that you could change in the procedure or setup. Describe your change below, test the consequences of the change with the meter and record below. Write a possible explanation for the results obtained.
   Possible ideas:
   Make a cell with two nickels and two pennies.
   Remove the electrolyte.
   Put both leads on one coin (or on one coin and the electrolyte).
   Have one cell right-side up and the next upside down in a series circuit versus a parallel circuit.

3. What kinds of things would you alter and test if you were trying to engineer a battery that produced high enough voltages to power a hybrid or plug-in car?
   Electrolyte material (matrix) so that more electrons could be generated
   It would be like replacing the paper towel with another material.
   Electrolyte – using something other than NaCl in water
   Electrochemical reaction that can be run in reverse to recharge battery
   Add more cells to the series but keep weight as low as possible
   Reaction that is safe – doesn't produce explosive gas or poisonous products
   Physical design that has the electrolyte in contact with as large a surface area of the electrodes as possible

4. The $500 question is……Why DO electrons flow when you connect a meter to a penny and a nickel (or any dissimilar metals) that are separated by an electrolyte?

   The reduction potential of one half-reaction is a lot greater than that of the other. So that at the anode, the substance has a much greater likelihood of being reduced.

ANECDOTAL COMMENTARY ON THE VOLTAIC PILE LAB

Before the lab, I had the students fill in the first nine terms on the student guide to get their minds focused on concepts related to the lab. If none of the students offered a good definition within a short amount of time, I dictated the definition to them. As this was the first year I had done this lab, I wasn't sure how much time it would take and didn't want to use up too much of the period writing definitions.

Some students really got into this lab. They observed all sorts of things them caused them to wonder. It offered a multitude of teachable moments. "Why are the voltages different between these two cells?" "Do you notice any differences when you look at the cells?" "Well, one penny on this one is dark and the other pennies are all shiny." "What *is* that dark color?" The girls discussed it a few minutes, coming up with several possibilities. Finally one girl guessed that it was copper oxide. We talked about how a layer of copper oxide on the surface might hamper the flow of mobile electrons from within the pure copper beneath.

Another group voiced a concern, "Our voltage readings on this cell keep fluctuating wildly!" I asked them to try touching the electrode to the side of the bottom coin instead of the top of the bottom coin. "It's steady now." We discussed what the difference was. If the electrode is on the side of the bottom coin, the electrons had to travel through both the electrolyte and the bottom coin. If the electrode was placed on top side of that coin, there were two possible environments. The electrode might be placed in an area of the coin that was dry. Here the electrons had to move through the electrolyte and the bottom coin to get to the electrode. Or, the electrode could end up on an area that was wet with electrolyte. This would create a short circuit, with electrons bypassing the bottom coin. Areas that were slightly wet could fluctuate between short circuit and complete circuit.

After students finished performing the lab, I showed slides of hybrid cars that are now on the market. I tied the slide show in with question 3 under the post lab questions and activities: What kinds of things would you alter and test if you were trying to engineer a battery that produced high enough voltages to power a hybrid or plug-in car? The students were very noisy during the slide show, but their noisiness was due to their excitement. They were telling each other about having ridden in one. They were also calling out questions, "How much did you say that one sells for?" "What was the mpg?"

APPENDIX V E
BUILDING A 3-D MODEL FOR EXTRA CREDIT

The following was displayed on the overhead projector. Interested students wrote the rubric down.

Extra Credit Options

Build a 3-D model of either a:

Fuel cell

Hybrid car battery
(the one that moves the car)

Battery for an electric plug-in car

It is ok if the models are not functional.

Present the model to the class, explaining the components and how the battery or cell works (or would work if it was functional). Include information on recent design advances and challenges that still need to be overcome.

Rubric

3-D Model:	Accuracy	2
	Neatness	2
	Looks like it took at least an hour to make	4
	Labels on components	1
Presentation:	Explain the model, its components and how the battery or fuel cell works	2
	Information on recent advances	2
	Challenges to overcome	2
		15 points

ANECDOTAL COMMENTARY ON BUILDING A 3-D MODEL

The rubric was up on the overhead. Part of the students copied it down. The class had notes and labeled drawings of a fuel cell. This choice would have required little research. As far as the batteries, we had done quite a few activities where we discussed differences between a regular lead acid car battery and these alternative types. We had also written out the half reactions for the hybrid car batteries. But students would have needed to do a little research to build the model.

As a class we agreed upon a due date for the project. Some students wanted the due date left open-ended, others wanted it due in 2 weeks. A compromise was reached. The due date was set for the day before Christmas break. That gave them four weeks. Students could bring their model in anytime before that, as each person finished theirs, to present.

As the weeks went by, I inquired about their progress on the project. Occasionally a student would ask a question about it, but none ever even started the project. By Christmas break zero projects had been turned in!

APPENDIX V F
HOMEWORK QUIZ TO ACCOMPANY THE PHOTOVOLTAICS ARTICLE

ADDRESS OF THE ARTICLE ON PHOTOVOLTAICS

http://www.nrel.gov/lcarning/re_photovoltaics.html

HOMEWORK QUIZ

1. What does PV stand for?

2. What happens when sunlight is absorbed by one of these cells?

3. Name three places you could find solar cells according to the article.

TEACHER'S KEY FOR THE
HOMEWORK QUIZ TO ACCOMPANY PHOTOVOLTAICS ARTICLE

1. What does PV stand for?

   Photovoltaic

2. What happens when sunlight is absorbed by one of these cells?

   Electrons are knocked off of their atoms

3. Name three places you could find solar cells according to the article.

   Any three of these:

   Calculators
   Watches
   Tracking Devices
   Shingles
   Roof Tiles
   Building Facades
   Glazing for Skylights or Atria
   Concentrating Collectors

ANECDOTAL COMMENTARY ON THE HOMEWORK QUIZ TO ACCOMPANY THE PHOTOVOLTAICS ARTICLE

In the units that I teach the rest of the year I give a homework quiz almost every day. I read the questions orally to give students experience processing auditory information. It forces them to write down the key information. I have always tried to model doing that on math problems, but most students skip the step of listing the information that is given. So following my oral quiz tradition, I read this quiz orally also. It just doesn't happen to contain the type of questions that require one to write down key information.

I also followed the other tradition that I use for homework quizzes. After all of the students have finished, one of the rolls an oversized red die that I brought back from Las Vegas. If an even number comes up, they don't have to turn the quiz in. We just go over the correct answers. They get two rolls to try for an even number. I have found that this technique gets them to really focus on the previous night's material for the five minutes that the quiz takes. I get valuable feedback on what students have learned about the topic. It also allows me to give these little quizzes almost daily without having too many papers to grade. The technique has mixed results as far as getting students to do their homework.

On the day of this homework quiz, the students rolled an even number and did not have to turn it in. In retrospect, I should have forgone the dice-rolling tradition and had them turn it in. Then the data could have been used in this thesis.

The quiz questions were very simple. Anyone who read the article should have been able to get them all right. Going over the answers after the quiz was a good starting point for the day's topic of photovoltaic cells.

APPENDIX V G
BUILDING A PHOTOVOLTAIC CELL LAB

STUDENT INSTRUCTIONS

The lab instructions are an adaptation from Flinn's kit "Build a Solar Cell: Photovoltaic Effect and Photosynthesis". The kit can be ordered online at www.flinnsci.com, catalog number AP6916. The printed lab directions that came with the kit were labeled as Publication No. 6916.

Changes that I made when I typed up instructions for my students focused on two goals. One: make the directions clear and simple. Two: reflect the changes I made when building PV cells myself.

I broke the lab into two days and wrote it up in two parts. Each part had its own materials list. Additions that I made to Flinn's materials list are as follows:

2 150-ml beakers rather than one (One for hibiscus infusion and one for HNO_3)
125-ml Erlenmeyer flask with rubber stopper to store hibiscus overnight
Matches to light tea light
Thin latex gloves to keep oils from hands off conductive plates
Ruler for use in coating plates
Scissors to open packaging
100-ml graduated cylinder to measure water
Masking tape for labeling vessels
Funnel and filter paper to separate hibiscus petals from dye

Changes I made to the procedure: In bold, before the procedure, I added "Read through the entire step before starting to perform the step." I also changed the order of the steps and broke many major steps down into sub-steps which I labeled as a, b, c, rather than writing them out in paragraph form. Steps that I changed significantly by adding more detail, making the directions more clear or modifying the technique are as follows:

Day One

1. Preparing concentrated hibiscus dye (Flinn's step 4 under preparation)

    a) Put 2 grams of dried hibiscus into a 150-ml beaker.

    b) Add 100 ml of distilled water.

    c) Label the beaker "Hibiscus Dye" using masking tape.

    d) Heat to boiling on a hot plate.

    e) Turn way down to allow it to steep for 15 minutes (set the timer). WORK ON STEPS 2-15 WHILE THE DYE IS STEEPING, THEN RETURN TO DO PARTS f AND g OF THE THIS STEP WHEN THE TIMER RINGS.

    f) Cool to room temperature.

    g) Filter by pouring through a funnel lined with filter paper. Catch in a clean, labeled Erlenmeyer. Close with a rubber stopper.

2. Rinsing the Plates (part of Flinn's step 1 under Preparation)

    a) Fill one of the plastic pipettes with 3 ml of ethyl alcohol.

    b) Clean the glass plates by holding them in gloved hands or with the tweezers, rinsing with the 3 ml of alcohol. HOLD THE PLATES CLOSE TO THE BENCHTOP SO IF YOU DROP THEM THEY ARE LESS LIKELY TO BREAK. You can lay paper towel down under them to catch the alcohol and to act as a safety cushion. AFTER RINSING, USE THE ALCOHOL-SOAKED PAPER TOWEL TO CLEAN OFF A SMALL AREA OF THE BENCHTOP.

3. Drying the Plates (the rest of Flinn's step 1)

    Pat the glass with dry lens paper. **Do NOT touch the glass plates with your bare hands, as it would get oil and dirt on the plates.**

4. Preheat the Hot Plate (Flinn's step 1 under Procedure)

    This step appears in an earlier position than it does in Flinn's version.

5. Identifying the Conductive Side of the Plates (Flinn's step 2 under Preparation)

    This procedure remained the same as Flinn's. However, I made each direction a separate step.

6. Preparing a 0.001M HNO_3 Solution (Flinn's step 3 under Preparation)

   The changes made here were for safety reasons.

   a) Measure 100 ml of distilled water into the 150-ml beaker. USE THE GRADUATED CYLINDER FOR MEASURING.

   b) Add 1 ml of 0.1 M HNO_3 to the water. ALWAYS ADD ACID TO WATER. DOING IT THE OTHER WAY AROUND CAN CAUSE AN EXPLOSION!

   c) Label the beaker "0.001M HNO_3 with masking tape.

7. Taping the Anode (Flinn's step 4 under Procedure)

   When I did the lab myself, I wasn't thinking and did this procedure to all of the plates, so the only change I have made was to include the phrase "...tape the two ends of ONE of the glass plates..." I also included Flinn's diagram under this step and referred to it by saying "(See diagram below)".

8. Making the Titanium Oxide Paste (Flinn's steps 2 and 3 under Procedure)

   If the paste sits very long it thickens up too much to spread well, so I added one sentence at the end: "PROCEED IMMEDIATELY TO THE NEXT STEP." I deleted the part about storing it in a capped bottle.

9. Coating the Anode (Flinn's steps 5,6 and 7 under Procedure)

   The only change was to let the students know that the titanium oxide film dries in about one minute <u>if they haven't put it on too thick</u>.

10. Baking the Coating (Flinn's steps 8 and 9)

    After the instructions say to heat the plate for 15 minutes, I inserted: DO STEP 11 WHILE WAITING.

11. Coating the Cathode (Flinn's steps 14 and 15)

    No changes needed.

12. Storing the Cathode Until Tomorrow

    Put the blackened plate under a Petri dish and store that in a dark cupboard.

13. Cooling the Anode (Flinn's steps 10 and 11)

No changes here except that I had inserted the cathode coating step between Flinn's steps 9 and 10.

14. Storing the Anode Until Tomorrow

    Set the white-coated anode plate down into the beaker of 0.001M HNO_3, being sure it is completely submerged.

DAY TWO

1. Dying the Anode (Flinn's step 12)

   No changes here except for occupying a different location in the sequence events. And this statement was added, "While waiting, you can coat the cathode with graphite if your group did not have time to do it on day one.

2. Rinsing the Anode (Flinn's step 13)

   a) Remove the dyed plate using tweezers.

   b) Using a plastic pipette, gently rinse the plate with 4 or 5 ml of distilled water.

   c) Using the same pipette, carefully rinse a second time with 4 or 5 ml of ethanol.

   d) PLACE THE BOTTOM END OF THE PLATE FIRMLY ON THE LAB BENCHTOP (NOT OVER THE SINK) SO YOU DON'T RISK DROPPING AND BREAKING IT. Very carefully, blot the plate dry with lens paper. DO NOT RUB.

3. Clipping the Plates Together (Flinn's steps 16 and 17)

   The only change made was to position Flinn's illustration 4b under their step 16 instructions and their illustration 4a under their step 17 instructions.

4. Introducing the Electrolyte (Flinn's steps 18 and 19)

   No changes made.

5. Testing the Photovoltaic Cell

   a) Set the multi meter to a 1-10V setting.

b) Touch the black lead to the purple titanium oxide anode on the clear glass end.

c) Touch the red lead to the black graphite cathode on its clear glass end. DO NOT REVERSE THE LEADS. IT MAY DAMAGE THE CELL.

d) Measure the voltage right where you are on the lab bench top in normal classroom light. Record the voltage in the table below. Reset the multi meter to measure current (1-20 Amps). Measure and record the current.

e) Place the solar cell on the overhead projector with the purple anode on the bottom. with the overhead light off, measure and record the voltage and the current.

f) Turn the overhead light on. Measure and record the voltage and current.

g) Set the cell back on the bench top. Have one student cover it with a small box or thick layers of dark cloth while the other holds the multi meter leads in place. The meter should not be covered. You want to be able to read it. Measure and record the voltage and the current.

h) Cooperate with the other groups by hooking all of your solar cells up into one series circuit. Measure the voltage and current. Try it again with only two cells in series.

i) Optimum performance is usually obtained using a parallel-series circuit. (See diagram.) Measure the current and potential difference (volts) for such a configuration. (Flinn's Figure 6 was inserted under this step.)

j) Think of five other tests you could run with your cell. Briefly describe each:

1.

2.

3.

4.

5.

k) Run the tests and enter the data below.

DATA TABLE FOR STEPS d through i

Light Conditions	Voltage	Amperage

DATA TABKE FOR STEP k

PHOTOS TO ILLUSTRATE STEPS IN BUILDING A PHOTOVOLTAIC CELL

Figure 113 Students Made a Photosensitive Dye from Hibiscus Flowers

Figure 114 Rinsing the Conductive Plates

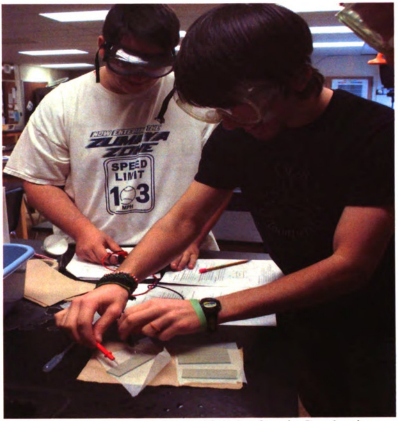


Figure 115 Determining Which Surface is Conductive


Figure 116 Preparing a Dilute Solution of Nitric Acid

Figure 117 Grinding Titanium Oxide to Prepare a Paste

Figure 118 Masking off the Anodes before Coating

Figure 119 Filtering the Hibiscus Infusion

Figure 120 First Step of Coating the Anode

Figure 121 Second Step of Coating the Anode

Figure 122 Coating the Cathode with Graphite


Figure 123 Dying the Anode with Hibiscus


Figure 124 Using Capillary Action to Introduce the Electrolyte

Figure 125 Testing Current and Voltage Output of the Finished PV Cells

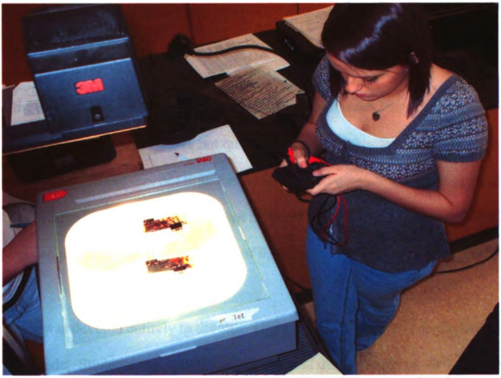


Figure 126 Soaking up Light for Another Test of Current and Voltage

ANECDOTAL COMMENTARY ON BUILDING A PHOTOVOLTAIC CELL LAB

This lab was broken into two days. On day one, the lesson began with students having an opportunity to ask questions about the homework reading, an article on photovoltaics. This was followed by a 3-question quiz over the homework reading. As a class, we then went over the correct answers to the quiz as an introduction into the day's notes: Comparing and Contrasting PV Cells with Galvanic Cells".

There were about 30 minutes remaining for the students to complete the lab procedure for day one which included:

Preparing Concentrated Hibiscus Dye
Rinsing the Conductive Plates
Drying the Conductive Plates
Preheating the Hot Plate
Identifying the Conducting Side of Each Plate
Preparing a 0.001M HNO_3 Solution
Taping the Anode
Making Titanium Oxide Paste
Coating the Anode
Baking the Anode Coating
Coating the Cathode

The list above looks very time consuming, but in reality each step takes very little time. However, the 30 minutes was not quite enough time. Another ten minutes would have been perfect. There was not time for the anodes to complete the baking process before the bell rang. And not all groups got their cathode coated. I cooled the anodes for all groups and put them down into beakers of 0.001M HNO_3 for storage until the next day.

Day two was devoted entirely to the lab. There is a 15-minute wait in the first step, dying the anode. Students that hadn't had time to coat their cathode on day one used this wait time to do it. Students all finished constructing the PV cells and ran some tests on theirs. Most groups did not get to run all of the tests I had included.

On both days during the lab, most students were absorbed and engaged, physically as well as mentally. I was very busy answering questions such as, "What is hibiscus?" and "Do we have to write anything down?" I also had to keep a close eye out for students making errors that would ruin their electrodes. By the end of day one all groups had gotten as far as coating the anode. I finished baking, cooling and storing them.

On day two, students seemed to get the most satisfaction out of coating the cathode. "Ms. Osmar, check this cathode out! Is that as nice job, or what?" We had enough glass plates that each group could make two anodes and two cathodes. This led to some problem solving. One group said to another, "How did you get both of your anodes into the petri dish?" Some groups used the top of the petri dish as a second dish.

Once the cells were constructed, there was a lot of discussion and argument about where leads should be placed. None of the groups got to the point of testing series versus parallel circuits or making up five of their own tests. But we couldn't afford the time of an additional day. There also wasn't time to draw and label the solar cell at the end of the hour. So I assigned them to make a labeled drawing of their cell at home from the lab discussion sheet. They were to do the drawing before attempting to answer the post lab questions.

APPENDIX V H
BUILDING A PHOTOVOLTAIC CELL POST-LAB QUESTIONS

These questions are meant to accompany a discussion handout which came with the Flinn kit.

8. Why are solid-state solar cells so expensive?

9. What is so great about dye-sensitized solar cells?

10. Considering the anode, which was coated with nanocrystalline titanium oxide and later dyed with hibiscus,

    a) What wavelengths does undyed titanium oxide absorb?

    b) What wavelengths does it absorb after being dyed?

    c) What was the reason for using a nanocrystalline form of TiO_2?

11. The functioning of the dye-sensitized solar cell is similar to the functioning of which biological process?

12. Why do leaves look red and orange in the fall?

13. In the photovoltaic cell that we made, what is the function of the

a) dye?

b) titanium oxide (anode)?

c) iodine/potassium iodide electrolyte?

d) graphite cathode?

14. What causes the electrons to flow from the anode to the cathode through the voltmeter (or some external circuit that would power your lights)? THINK OF WHAT WE LEARNED IN THIS CHAPTER.

TEACHER'S KEY FOR BUILDING A PHOTOVOLTAIC CELL POST-LAB QUESTIONS

1. Why are solid-state solar cells so expensive?
   They require large, high purity silicon crystals for greatest efficiency. These crystals are very expensive, both the raw materials and the manufacture.

2. What is so great about dye-sensitized solar cells?
   The two functions of light absorption and electron transfer and separate, so can be engineered for maximum efficiency separately.

3. Considering the anode, which was coated with nanocrystalline titanium oxide and later dyed with hibiscus,

   a. What wavelengths does undyed titanium oxide absorb? **Ultraviolet**

   b. What wavelengths does it absorb after being dyed? **Visible**

   c. What was the reason for using a nanocrystalline form of TiO_2?
      It provides more surface area so more light is absorbed.

4. The functioning of the dye-sensitized solar cell is similar to the functioning of which biological process?
   It is similar to the way chlorophyll makes use of light in photosynthesis.

5. Why do leaves look red and orange in the fall?
   Those pigments are always there, but are normally masked by the green color of chlorophyll. In the fall when the chlorophyll is inactivated you can see through it to the orange and red.

6. In the photovoltaic cell that we made, what is the function of the

    a. dye? **It absorbs visible light and electrons in the atoms of dye are promoted from the ground level to a higher energy level.**

    b. titanium oxide (anode)? **It oxidizes the dye (takes an electron away from it).**

    c. iodine/potassium iodide electrolyte? **It is a redox catalyst. The iodide anion donates electrons to the dye.**

    d. graphite cathode? **The graphite reduces I_2 to I^- by using the electons traveling to it from the anode.**

7. What causes the electrons to flow from the anode to the cathode through the voltmeter (or some external circuit that would power your lights)? THINK OF WHAT WE LEARNED IN THIS CHAPTER.

    The potential difference between the titanium oxide and the graphite causes the movement of electrons.

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