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The Effectiveness of Student-led Demonstrations in a High School Physics Class

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THE EFFECTIVENESS OF STUDENT-LED DEMONSTRATIONS IN A HIGH SCHOOL PHYSICS CLASS

By

Paul B. Ciske

A THESIS

Submitted to
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ABSTRACT

THE EFFECTIVENESS OF STUDENT-LED DEMONSTRATIONS IN A HIGH SCHOOL PHYSICS CLASS

By

Paul B. Ciske

During the 2001-2002 school year, the students in the physics class at Mio AuSable High School prepared and performed demonstrations for their fellow students on eleven physics topics: fluid mechanics, thermal energy, wave properties, sound, reflection, electrostatics, dc circuits, Newton's Laws, force components, circular motion and rotational motion. Data were collected using predetermined pretest and posttest questions to measure the effectiveness of using demonstrations in this way. Improvement was also studied using a student opinion survey and collections of student responses to test questions.

The data showed considerable improvement by the students in the eleven topic areas on the posttest compared to the pretest. The data were also examined to compare the scores of the students who performed the demonstrations to those of students who observed the demonstrations. The data showed that the presenters typically performed better on the posttest than the observers.

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I. Introduction

One tool used by science educators in the teaching of science concepts is the classroom demonstration. Many teachers can recall a time in their own education when a well-performed demonstration sparked their interest; thus, they wish to light that spark in others in the same way. A demonstration can capture the attention of a class and focus it on a single point: the description and explanation of what was just observed. For that matter, practicing science teachers still like to see a good demonstration. Personal observations at science teacher conferences show the sessions that are presenting demonstrations are always well attended, while those covering educational philosophy are less popular. Many of the teachers at the demonstration sessions are looking for unique ways to demonstrate a concept, while others simply appreciate good demonstrations and are there to observe and learn themselves.

The collection of anecdotal evidence in support of classroom demonstrations is impressive. Moreover, the journal Physics Teacher published a collection of five papers on the subject of classroom demonstrations (Frier, p. 384; Pinkston, p. 387; Hilton, p. 389; Carpenter and Minnix, p. 391; Johnston, p. 393). Virginia Military Institute physics professors Rae Carpenter and Richard Minnix express the collective opinion of these papers:

> "A good lecture demonstration seems to whet the appetite of young students. Some even stay around after class to discuss what they saw and to try it for themselves. Moreover, the students themselves believe the demonstrations are valuable. An overwhelming majority of our student course evaluations show that they feel the lecture demonstrations increase their understanding and that the time devoted to them is well spent." (392)

Based on personal experience and conversations with other teachers there is little doubt that lecture demonstrations are popular with students. It is not uncommon after the completion of a demonstration for students to request to see it again. This generally cannot be said for the derivation of a mathematical formula.

Over time, great physicists have used clever demonstrations to illustrate their subjects. It is rumored that Michael Faraday, when lecturing, would have forty or more demonstrations to perform in a single lecture. The response was overwhelming. His lectures were typically standing room only with most of the attendants not even students in the class (Sixtus, 1993). Hans Christian Oerstead made his famous discovery of electromagnetism during a lecture demonstration. Recognizing the importance of demonstrations, Oerstead is quoted as saying, "The mere dry lectures as were given in Berlin without the art of experimentation do not please me, for after all, all scientific advances must start from experimentation." (Hilton, 1981).

In modern times it is hard to imagine a single demonstration that had more impact on the public than that of physicist Richard Feynmen during the investigation into the 1986 explosion of the space shuttle, <u>Challenger</u>. A major debate was brewing on the subject of the shuttle's O-rings. Some believed that the O-rings lost flexibility at low temperatures, causing the fuel to mix too quickly which lead to the shuttle's explosion. The manufacturer of the O-rings insisted that they were still very flexible at low temperatures and were not the problem. Before a congressional hearing, the Nobel Prize laureate used a pitcher of ice water and a c-clamp to demonstrate how the shuttle's O-rings lost their flexibility at low temperatures causing the fuel leak that led to the disaster. (Feynman, 1988) This story shows the power of a demonstration. The commission members no longer had to hear testimony on this point. They had seen the results with their own eyes.

All demonstrations, however, are not equal. Just as a poor laboratory activity can amount to nothing more than a craft project, a poor demonstration can be nothing more than a magic trick. The difference between a magic trick and a science demonstration is that a magician keeps the secrets to himself, while a science teacher's goal is for everyone to discover the secret, and through that discovery learn a science topic. Were the people who packed Faraday's lecture hall interested in learning new and exciting things about physics, or were they there to watch a show? The importance of balancing showmanship and content is well described by Nanuet High School physics teacher John Johnson.

> "First, the demonstration must educate, but if it also entertains, so be it. You always want impact; you want the concept to be remembered. I see nothing wrong in staging and presenting as many demonstrations as possible in a dramatic and theatrical way, as long as it doesn't detract from the physics being taught. Anything well displayed is half sold. And we are selling ideas and competing with every other discipline." (Johnson, 1981)

Of course demonstrations must be engaging and even entertaining to a point. The mastery of science concepts requires a good deal of effort on the part of the student. Students must be enticed to put forth the effort and sustain the effort until mastery is reached. (Anderson and Okhee, 1997) The entertainment value of demonstrations can serve the purpose of the "bait" needed to lure the students to focus their attention and efforts long enough to master a concept.

Not only do personal anecdotes support the use of demonstrations during class lectures, but there also exists quantitative data to support this idea. During the 1980's, F.D. Boulanger compiled data from over fifty independent studies over a fifteen-year period on effective methods of science education. Through this meta-analysis, Boulanger

was able to note several important principles related to student outcomes (in Hofwolt, 1989). One such principle had to do with the greater ability of students to understand material that is presented in a less abstract manner:

> Instructional materials may be placed on a continuum from concrete to symbolic: manipulatives are more concrete than are pictorial stimuli, which in turn are more concrete than printed text material. Similarly, a student's lab experiment is more concrete than is a teacher's demonstration, and the teacher demonstration is more concrete than a lecture. All the studies Boulanger looked at showed that greater realism or concreteness in supporting instructional materials led to greater cognitive achievement (Hofwolt, 1989).

Being more concrete than a lecture, a demonstration illustrates a topic much more effectively than a verbal description alone.

It is worth noting that the study referenced above states that a laboratory experiment is more concrete and consequently more effective than are lecture demonstrations. The enthusiastic support in this paper for classroom demonstrations should not be interpreted as a suggestion that they should replace the legitimate role of hands-on lab activities in a science curriculum. In fact, the Boulanger study lists hands-on activities as one of the six instruction clusters that have the most significant effects on student outcomes (Hofwolt 1989).

There are, however, certain advantages that demonstrations have over laboratory experiments. A typical demonstration requires much less class time than does an experiment. Demonstrations only require one set of lab equipment to perform it for a large group and can be very appropriate when the required equipment is expensive. Most demonstrations only work well after they are practiced by the presenter or lose their effectiveness if there is no surprise for the observer.

One clever demonstration on the index of refraction counts on the surprise factor. A Pyrex glass test tube is placed in Wesson oil before it is shown to the class. Pyrex glass and Wesson oil have the same indices of refraction so the test tube cannot be seen in the oil. The presenter announces that he has discovered that Wesson oil fixes broken glass. He produced a test tube, smashes it to bits with a hammer and places the pieces in the beaker of oil. After stirring and allowing the suspense to build, the presenter reaches in with a pair of tongs and to the surprise of the class, removes the solid test tube that is hidden in plain sight. An experienced demonstrator will have a second test tube in the beaker of oil ready to go, because the class will want to see it done again. (Ewing, 2000) This demonstration could not be done as a lab experiment. The students would know that the intact test tube was in the oil and thus there would be no surprise and very little effect.

With the consensus of opinion being that demonstrations are beneficial, it is curious why more of them are not done. The reasons for not doing demonstrations are mostly logistical. Demonstrations take time to set up and practice. With accumulating materials, assembly and practice, a good demonstration can require a few hours of preparation. With the other burdens of teaching, a few hours of preparation for fifteen to twenty minutes of class time is a very extravagant use of the teacher's time. The problem is well stated in the following review of a book of physics demonstrations.

> "The effective demonstrator must spend hours searching the literature for good ideas; he must also devote time, skill and patience in putting things together and rehearsing over and over again to make sure that no vital matter has been overlooked. It is a small wonder that many teachers … have found it simpler to confine their demonstrations to drawings, charts and equations on the blackboard, instead of trying to show the class how things really go." (Pinkston 1981)

Considering the preparation requirements, the question changes from "Why aren't more demonstrations done?" to "Why are any done at all?" Major universities, recognizing the importance of demonstrations, hire staff for the sole purpose of preparing and sometimes even performing demonstrations, thus relieving the professor from these duties. This, however, is not true for high schools. Any demonstrations to be done must be prepared and performed by the classroom teacher.

Alternatives to physical demonstrations do exist. In large demonstration sessions at science teacher conferences, it is not uncommon to see teachers carrying video cameras to record the demonstrations and play them back for their own class. Similarly, collections of well-performed demonstrations on video are available to purchase from science supply companies, such as Sargent-Welch and Arbor Scientific. These collections do have certain logistical advantages to live demonstrations, but it is hard to believe that they could be as effective as seeing the demonstration live. University of Minnesota physics professor George Frier likens the use of demonstrations on film to that of seeing pictures of a friend's children. Actually meeting the children is required to get to know them. (Frier, 1981)

The challenge for a high school science teacher is to incorporate meaningful demonstrations into his class while still managing other professional responsibilities. Some teachers have found it appropriate to use students as presenters of science information to other students. In one example of this, the high school physics class at Lawrence Central High School in Indianapolis, Indiana presented a "Physics Road Show" to elementary classes in their district. This physics class prepared demonstrations in several topic areas. While no quantitative data on the effectiveness of this program was reported, the anecdotal evidence was encouraging. It claimed benefits for both observers and presenters. (Edelman and Goeglein, 1995) A similar example involved a physical science class at Omaha South High School in Omaha, Nebraska. This class began by showing demonstrations for special education classes in the high school building. The program has since expanded to include presentations to elementary classes and in a local science museum. As with the previous example, there was no quantitative data, but anecdotal evidence was very supportive of the approach. (Galus, 2000)

In another example of students as presenters, middle school teacher Daniel Mennelly set up an enrichment program with a structure he calls a “pyramid scheme”. In this format, he targeted a small group of students to prepare an enrichment lab activity. These students then helped others through the activity. The resulting data are also anecdotal with the effort considered to be a success. (Mennelly, 2000) In all of these examples, students successfully presented science information to other students. It was asserted in each case that the effort was beneficial for both the presenter and the observer. This research project further explores the effectiveness of using students as classroom presenters.

II. Implementation

This research project was undertaken to find and evaluate an effective way to incorporate more physical demonstrations into a high school physics class at Mio AuSable High School in Mio, Michigan. This project was implemented during the 2001-2002 school year. Mio is a small, rural community in northeast Michigan. The school contains grades K-12 all in the same building with a total student count near 900. In a small school, each teacher must wear many hats and consequently preparation time is a rare commodity. The course in this study was a year-long high school physics class. It is intended for seniors who have taken or are taking trigonometry. The course already had many laboratory experiments and improvements in this area were not needed. However, very few demonstrations were done. It was the teacher's desire to increase the overall number of demonstrations prepared in such a way that they could be done easily every year.

The idea was to have groups of students prepare and perform the demonstrations for the rest of the class. The students would collect the materials, assemble the equipment, study and master background information, practice the demonstration and present it to the rest of the class. The rationale for this approach is that time needed to prepare the demonstration would be provided by the group of students and not by the teacher. On the surface, it may seem that this approach treats the students of the physics class as mere assistants, requiring them to make class preparations that could easily fall under the teacher's duties. However, preparing a demonstration is not like making copies, carrying the teacher's books or washing his car. The students performing the demonstration stand to gain from their independent, in-depth study of a physics topic.

The class in which this approach was implemented and documented was made up of nineteen students, ten males and nine females. All nineteen students were Caucasian, and all had completed the minimum two classes in science required for graduation and were taking the physics class as an elective. This was a particularly large physics class for Mio AuSable High School. A typical physics class would have 6-10 students. No data was collected on the economic background of the students' families, but it is believed that it is a mixture of low to upper middle class family incomes. Being from a small community, the students knew each other quite well, most being in classes together since early elementary grades. Finally, for no other reason than to help the reader appreciate the flavor of the class, it is worth noting that the class contained two sets of twins. It is not believed that these family relationships affected the study, but they did make the class more colorful.

In the design of the student-led demonstrations three factors were considered. First, the demonstrations had to be sufficiently interesting to make it worthy of the student group's effort to prepare and present it. Second, the descriptions of the demonstrations had to be clear enough that a group of students could read them and, based on the reading, prepare the demonstration with little or no help from the teacher. Third, the descriptions had to contain sufficient background information that the student presenters would be able to adequately describe the scientific principles behind their demonstrations.

Picking good demonstrations for the students to prepare and present was the first hurdle to cross. Many of these required special equipment that the rest of the class did not have access to or provided a surprise ending. During the Summer of 2001 physics demonstrations were collected and developed. Most of the demonstration ideas came from books, internet web sites and discussions with other science teachers. Other demonstrations were those that have been performed in physics classes for years and not attributable to a single source. For each of these demonstrations, a written description was prepared so that a student group could prepare the demonstration with little help from the teacher. Appendix A is a complete description of the demonstrations from the eleven topic areas discussed in this paper.

When each topic was introduced, one group was given a written description on how to prepare and perform the related demonstration or group of demonstrations and a deadline when they would need to perform it for the class. The groups were instructed that every member of the group had to work on every part of the demonstration. It would not be acceptable for one student to handle the materials, a second student to organize the demonstration and a third student to present it. Students read the instructions and prepared the demonstration independently for the most part, seeking out the teacher's help only when they had a particular question.

Finally, the students needed to acquire sufficient background information to be able to adequately describe the scientific principles demonstrated. As was stated previously, it is easy for a demonstration to turn into nothing more than a magic trick. If the presenters have little idea about what is going on, then the point of the demonstration is nearly lost from the start. According to the Third International Math and Science Study (TIMSS) the quality of science instruction is directly related to the level of understanding of the presenter. (Schmidt and Wang, 1999)

This point presents a particular problem for this project. The students take the class because they do not know the subject. The students build their background knowledge through reading supplemental material, participating in class and through the experience of preparing the demonstration itself. Along with each set of demonstration instructions, a written description of the scientific principles being taught was included for the presenters to read. Also, the students were participating in class concurrent with preparing their demonstration. Generally, the demonstration was performed near the end of a unit. This gave the presenters a chance to learn with their peers before making the presentation.

While most groups approached the demonstrations with a great deal of enthusiasm and a desire to present them well, certain precautions were made by the teacher to ensure that the presenters understood their material. During the first semester, homework questions particularly developed for the project were identified to the student presenters as covering the topics being described in the demonstrations. While these questions were assigned to all students, they were worth more points for the presenters than for the other students in the class. The added importance of these questions gave the presenters the extra incentive to get them correct thus showing that they had mastered the material. Examples of these homework questions can be found in Appendix A-II.

Student homework assignments in this course including those used for the purpose of evaluating the student-presenters' knowledge were computer generated using the LON-CAPA software system developed in the Laboratory for Instructional Technology in Education at Michigan State University. While this system has many potential applications, in this course it was used exclusively for generating and managing

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homework assignments. This system randomly generates elements of a homework assignment and provides an individual version for each student. For numeric problems, the system randomly generates numbers from a given range. Conceptual questions are in the form of true/false, fill in the blank, matching or selecting from options (greater than/less than, increase/decrease...). Conceptual questions are randomized by selecting some questions from a group of possible questions and by changing the order that the questions are presented. Examples of these homework questions can be found in Appendix A of this paper.

Students submit their answers via the internet. The system evaluates the answers and gives immediate feedback to the students. A student who gets an answer wrong can be given the chance to correct it. The teacher has the option to set the number of times that students may submit answers and the weight of each question. The teacher can also set tolerances to specify how close the answer must be to the computer's answer and the number of significant figures that are acceptable in the answer. One drawback of the system is the inability to assign short answer or essay questions to the students. There is no way for the system to evaluate such a question. Students were asked this type of question on laboratory assignments and on tests so that the teacher could grade them.

At the beginning of a topic, each student was given an individualized problem set to complete during the unit. The assignment was usually due near the end of the unit. During long units the problem set would be divided into two parts with one part due near the midpoint of the unit. While some students would wait until the end to work on the assignment, others would work on it steadily through the unit. As students encountered problems they discussed them with the teacher or with other students. Because of the individual nature of the assignments, students could discuss how a problem was done without simply being given the answer.

In the second semester, the presenters were required to submit to the teacher written observations and explanations from their demonstration. The written work had three elements for each demonstration: 1) a prediction about what would happen during the procedure, 2) a description of what actually happened during the procedure, and 3) an explanation of the physical basis for the observations. During the second semester demonstrations, the observers wrote about the demonstration in the same way. This change was made to align the activity of the presenters with the activity of the observers, which was changed during the second semester also. This change is explained later in this section.

The final guarantee that the material was being presented correctly was the classroom teacher. As always, it is the teacher's responsibility to ensure that the material being presented is correct and well explained. As the students presented their demonstration, the teacher was alert to inaccuracies and unclear descriptions. When they occurred, the teacher would have the group provide a correct explanation. If the review was insufficient, then the teacher would explain the point to the class so that both the presenters and the observers would understand it. In actual practice, it was not uncommon for the teacher to ask a group to explain a concept again, but rare that the second explanation was inadequate.

Based on observations and research during the first semester, the procedure for presenting the demonstrations was changed for the second semester to include a more active role on the part of the observers. During each demonstration, the students observing the demonstration were required to make predictions, record observations and explain those observations in writing. This technique of immediately assessing student understanding of a demonstration was used in the Chemistry Department at Louisiana Technological University as a way to enhance and evaluate critical thinking skills. (Radford, Ramsey and Deese, 1995) In a study performed at this university, two sections of a chemistry class were evaluated. In the first section, the demonstrations were presented to the class, but no immediate feedback from the students was required. In the second section, the students were immediately assessed on their observations and explanations of the demonstrations. Their data showed significantly higher test score for the second group (Deese, Ramsey Walczyk and Eddy, 2000). This process was added in the second semester of this course to see if it would increase the observers attention to the demonstrations and their understanding of the concepts presented.

During the first semester, demonstrations from six topic areas were evaluated: fluid mechanics, thermal energy, waves, sound, reflection and electrostatics. During the second semester, demonstrations from an additional five topic areas were evaluated: DC circuits, Newton's Laws, force components, circular motion and rotational motion.

The order of topics is different from that of a traditional physics class. The Mio Physics class has been organized in this way for several years. It was originally changed to accommodate the math abilities of the students. Many of the students were taking the Trigonometry course concurrently with physics. At the beginning of the year, most of these students were unfamiliar with even basic trigonometry operations involving right triangles. Moving the mechanics topics to the second semester allowed the students to acquire more background mathematical knowledge, and they were better able to comprehend the material presented.

Summary of Topics: The following is a brief summary of the topics in the order that they were presented. A complete description of the demonstrations performed is found in Appendix B of this document. This is not a comprehensive list of all topics taught in this introductory physics class, but only those topics for which student-led demonstrations were evaluated.

Fluid mechanics (Appendix B-I) was the first topic area presented. The student group demonstrated Archimedes Principle by floating objects of equal mass in different liquids to show that the density of the liquid affected the volume of liquid displaced. A small pressure fountain was constructed to demonstrate the flow of fluids over a pressure gradient and the effects of height on pressure, and balls were made to float in a stream of air to demonstrate Bernoulli's Principle.

Thermal energy (Appendix B-II) was the second topic. This group presented a collection of four different demonstrations illustrating this topic. Thermal expansion was demonstrated with a brass ball and a ring that was slightly smaller, and boiling water in a paper cup showed that objects in contact with each other stay at an equal temperature. The effect of specific heat and heat capacity was shown in two ways. First, the group presented equal masses of water and small lead pellets at the same temperature. Equal masses of wax were placed in each. The wax placed in the water melted much more showing its higher specific heat. Heat capacity was demonstrated by placing equal sized samples of various metals at the same temperature on a thin sheet of wax. The samples melted through in an order not equal to their specific heats. Through these demonstrations it was shown that heat capacity depends both on mass and the specific heat of the material.

Wave Properties (Appendix B-III) was the third topic area demonstrated. For this topic a ripple tank was used to demonstrate several principles. Waves were generated to show that they travel along straight-line paths. The frequency of the waves was changed to show the inverse relationship between frequency and wavelength. Various objects were placed in the tank to show the properties of reflection, refraction and diffraction. Finally, multiple waves were produced to show the property of interference.

Sound (Appendix B-IV) was the fourth topic area presented. The group demonstrated resonance in several ways. They showed a coupled pendulum, they resonated several open and closed tubes at various frequencies and they used a laser shining on a vibrating membrane to show how vibrations are dependant on both frequency and amplitude. Finally, they extended the topic to include the interference of sound waves by projecting similar sound waves and demonstrating that their beat frequency is equal to the difference in frequency between the two sounds.

The reflection of light (Appendix B-V) was the fifth topic area presented. The group used a laser, mirrors and a fog machine to illustrate the law of reflection. They reflected the laser beam off a mirror set at various angles and showed that the law applies to curved mirrors as well. They then combined several of these ideas to construct a laser spirograph from two spinning concave mirrors. The device projected circular patterns on a screen that would change with the rotational speeds of the mirrors. The group then explained how the device worked using the principles of reflection that they had previously explained.

The final topic area demonstrated in the first semester was electrostatics (Appendix B-VI). The group prepared several demonstrations using a Van deGraff generator. They showed spark discharge, how objects are charged by conduction and induction and the Basic Law of Electrostatics. In the process they built a set of static controlled symbols and a static bell that was first described by Benjamin Franklin.

The first topic presented in the second semester was DC circuits (Appendix B-VII). The group constructed resistors out of play dough and assembled them into various circuits. Through these circuits they compared the distribution of current and voltage in both series and parallel circuits.

The next topic area presented was Newton's Laws (Appendix B-VIII). The group exhibited three demonstrations. In the first, they suspended a mass and showed the effects of sudden forces and gradual forces on it. Through these demonstrations they were able to discuss both the first and second laws. During the second demonstration, they hung a weight from a spring scale and noted its reading. They then showed that hanging two spring scales linearly did not affect the reading. Both scales read the same as one scale did supporting the same weight. This showed Newton's Third law of equal and opposite forces. The third demonstration also demonstrated the third law by rolling a coffee can containing a counter weight across the floor. The can will roll a certain distance and then return. The observers, not being aware of the counterweight, would see the can's behavior violating the first law, but when the counterweight was revealed, the third law was again reinforced.

Force components (Appendix B-IX) was the third topic area of this semester. The group compared parallel forces and normal forces using a toy car propped on an inclined plane. Weights were suspended from pulleys to balance the normal force and the parallel force. The board making the inclined plane was then removed, showing that it was no longer necessary to keep the car inclined as it was on the ramp.

The fourth topic area of this semester was circular motion (Appendix B-X). This group carried out two demonstrations. The first showed that objects can have different tangential speeds even if their angular speeds are identical. This was demonstrated by one person swinging two tennis balls on different length strings. The swings were such that each ball had the same rotational period. When they were released, the ball with the longer string traveled farther showing it had a larger tangential speed. The second demonstration showed that objects can travel in a vertical circle once they reach a sufficient speed by swinging a bucket of water in a vertical circle. These demonstrations were both performed outside.

The final topic area was rotational motion (Appendix B-XI). This group also presented two demonstrations. The first showed a balanced candle burning at both ends. As the candle burns, the center of mass shifts slightly causing the candle to rock back and forth. The second demonstration set up a hammer suspended in a way that seemed to defy gravity. The group then used this setup to show how the balance of forces and balance of torques keeps the system in equilibrium.

The effectiveness of the demonstrations was evaluated through a series of questions that were developed for each demonstration. These questions can be found in Appendix A-I of this paper. The questions were presented in a pretest at the beginning of the chapter in which the demonstration was to be presented. The same questions were then asked again on the chapter posttest. A few selected questions were then asked again on the first semester exam to determine long-term retention of the information

A scoring rubric was developed for each question, which is also found in Appendix A-I. The pretest and posttest questions were scored and the data compiled for each topic area. Average pretest and posttest scores were examined for each chapter to assess student gains. The data were then disaggregated to compare the performance of the students presenting during a particular chapter to that of the rest of the class. An opinion survey was also given to the class as an indicator of the students' opinions about the impact of classroom demonstrations.

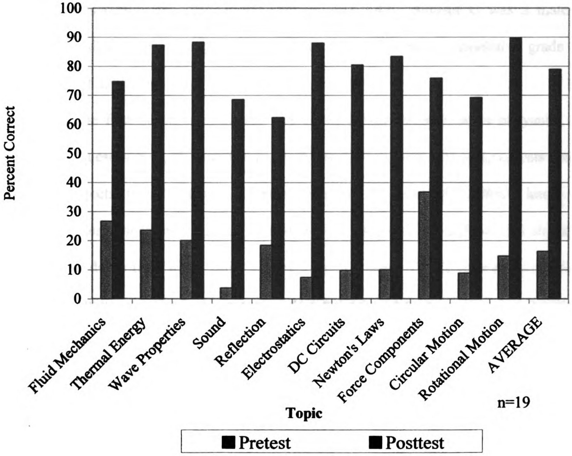
Three students were also identified whose responses on the pretests and posttests would be looked at in more detail. Their individual responses to selected pretest and posttest questions were collected and will be presented in the results section of this paper. The students selected had varying abilities to show how this project impacted students at varying levels.

III. Results

The effectiveness of student-led physics demonstrations was evaluated in several ways. Pretest and posttest data were examined for each topic area both for the class as a whole and comparing observers to presenters. A few topics were evaluated for long-term retention. Actual responses from three different students of varying ability were closely examined. Finally, an opinion survey was used to see student opinions on the effectiveness of student-led demonstrations.

In each of the eleven topic areas, students scored considerably higher on the posttest than the pretest. The results for each topic area are found in Table 37, which is located in Appendix C of this paper. They are summarized graphically in Figure 1.

Figure 1: Comparison of Pretest and Posttest Scores



The average improvement was 62.5 percentage points above the pretest. The topic that showed the greatest improvement was electrostatics, which had an improvement of 80.6 percentage points over the pretest. The area that showed the least improvement was force components, which had only an improvement of 39.2 percentage points over the pretest. It is noted that the lack of improvement in this topic area is a result of high performance on the pretest and not a poor performance on the posttest.

The improvement between the pretests and posttests is also evident through individual student responses. Three students' responses will be examined. The three students will be referred to as Student A, Student B and Student C. Student A was a female who maintained an A average throughout the year. She had a cumulative grade point average of 4.00. Student B was a male who maintained a B average throughout the year. His cumulative grade point average was 3.47. Student C was a male who maintained a C-/D+ average throughout the year. He had a cumulative grade point average of 2.90.

The first question examined was asked during the section on buoyancy. The specific question was, "Using Archimedes' Principle, explain why some objects sink and some objects float." On the pretest, Student A answered "I don't know what Archimedes' principle is, but objects that are less dense than water float, and objects that are more dense than water sink." She received 0 points for this response as it did not discuss buoyancy. She had some understanding on the topic as it relates to density, but could not explain why an object with a lower density will float. Students B and C both left this question blank on the pretest.

On the posttest, student A answered the question, "An object will float if the weight of the object and the water it displaces is equal to the buoyant force of the fluid. A buoyant force is an upward force from the fluid that goes against gravity." After the demonstrations, this student knew that Archimedes' Principle was related to buoyancy and could define a buoyant force. She did have problems explaining how the buoyant force is caused and how that affects an object's ability to float. This answer was scored for one point.

On the posttest, student B answered, "Buoyant Force equals the weight of the displaced fluid. When an object floats that means that the buoyant force that is pushing upwards is greater than the weight of the object. When something sinks, the buoyant force is less than the weight." This student knew that Archimedes' Principle is related to buoyancy. He could state the principle clearly and was able to describe why objects sink and float. This answer was scored for two points.

Student C answered, "An object will float if its buoyant force is equal to or greater than its weight. If its buoyant force is less than its weight it will sink." This student demonstrated that he now knew how a buoyant force must compare to an object's weight for it to float. He however did not explain how a buoyant force is produced or what determines its magnitude. This answer was scored for one point.

All three of the students showed improvement over their pretest responses. In their responses they related buoyant forces to the object's ability to float and two of the responses attempted to relate the buoyant force to the displacement of fluid.

During the section on thermal energy, the students were presented with the question, "You are heating a pan of water on the stove; does the pan get hotter than the water, stay cooler than the water or stay the same temperature as the water? Explain your answer." On the pretest, student A answered the question, "The pan does get hot, but not as hot as the water because the water heats up faster at lower temperatures than the metal the pot is made of." Student B answered, "same temp." Student C answered, "hotter than the water – the pan is absorbing the heat". The answer for student B was scored for one point, while the answers from students A and C were scored for zero points. All three answers indicated little understanding on this topic.

On the posttest, student A answered, "The pan and the water are at the same temperature. Since they are in contact the pan, which has a lower specific heat, will continuously give the water heat energy to reach equilibrium." Student B answered, "The temp of the pan and water stay the same because since they are touching each other, they absorb the same amount of heat." Each answer correctly identifies the two materials as being at the same temperature, but incorrectly identifies why they are at the same temperature. Student A identifies specific heat as the factor that determines the direction of energy flow while student B relates it to the absorption of heat energy. Each was scored for one point. Student C answered, "They are at the same temperature. As the pan gets hotter the water absorbs the heat causing them to be the same." He identifies the materials as being at the same temperature and states that the heat flows from the pan to the water keeping them at the same temperature. While this answer could have been more specific, it was scored for two points.

Again these answers indicate an increase in student understanding. Not only are the scores higher on the posttest, but also the descriptions include more information

indicating that the students are not guessing, but have knowledge on which to base their answers.

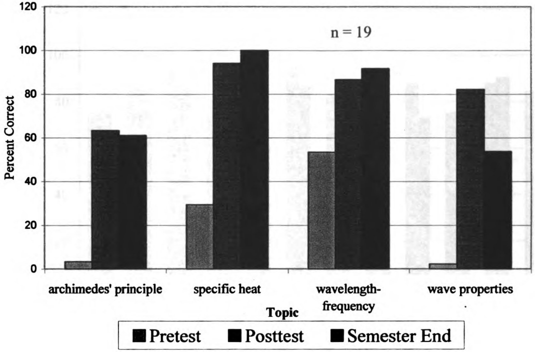
During the section on sound, the students were asked the question, "How do sound waves vibrate in a tube closed at one end (such as a pop bottle) compared to a tube open at both ends (such as a trombone)? On the pretest, student A answered, "In the trombone the vibrations are consistent & uniform as they travel out, but in the pop bottle the vibrations are uneven because they hit the closed end." Student B answered, "The sound waves reflect off the end of the pop bottle and are muffled. The trombone sound waves are very loud." Student C left the question blank. None of these answers indicate an understanding of how waves resonate in a confined space. All three were scored zero points.

The posttest showed a considerable increase in understanding for all three students. Student A answered, "A closed tube vibrates at odd harmonics and a node is at the closed end and an antinode is at the open end, whereas a open tube vibrates at even harmonics and an antinode is present at both ends." Student B answered, "In closed tubes there is an antinode at one end and a node at the other. In open tubes there is an antinode at both ends of the tube." Student C answered, "There is a node at the bottom of the closed tube. Both ends of the open tube are antinodes with a node in the middle causing the vibrations to be different." All three responses show an understanding of the location of nodes and antinodes for a standing sound wave. Also, all three correctly describe the differences between the two types of tubes. Each answer was scored for two points.

Each of these examples shows student improvement in the topic areas covered by the demonstrations. This is true across all eleven of the topic areas evaluated in this paper. It is also worth noting that the highest achieving students did not always give the best answers. In the examples shown above, Student A was more likely to attempt an answer on the pretest, although it often was not right. She was no more likely to get a correct answer on the posttest than were students B and C. It was anecdotally noted during the class that overall performance was not necessarily related to success on the demonstration related questions. While some upper level students were very interested in the demonstrations, others did not seem to relate well to them. Some lower achieving students seemed quite interested in the demonstrations and therefore performed equally well.

At the end of the first semester, four topics, Archimedes' principle, specific heat, wave properties and the frequency-wavelength relationship, were revisited to measure long term retention of the information covered. Each topic was covered nine to fifteen weeks before the semester end. On the semester exam, the students were asked the same questions as were asked on the pretest and chapter test. The questions are found in Appendix A-I. The results are listed in table 38, which is found in Appendix C of this paper. The results are also summarized graphically in Figure 2. As is shown, students were able to recall information on the selected topics at the end of the semester. Student performance in the four topics measured was considerably higher than for the respective pretest question. Students performed comparably to the posttest in each area. In two areas students performed even higher on the semester exam than on the chapter posttest.

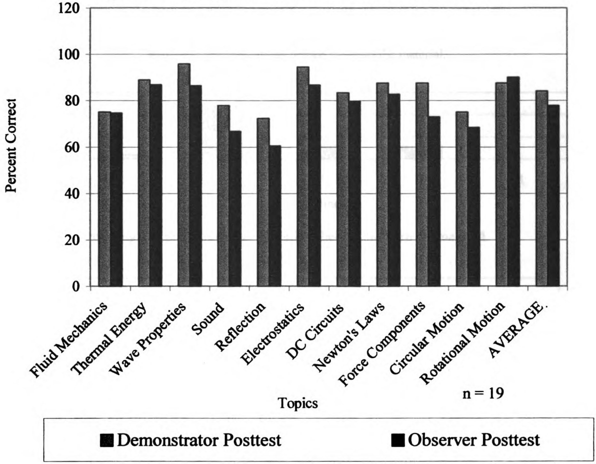
Figure 2: Semester End Comparisons for Target Questions



Data was also collected for each topic comparing the performance of the students presenting during that topic to the students who only observed during that topic. This data is reported in Table 39, which is found in Appendix C of this paper and summarized graphically in Figure 3.

As Figure 3 illustrates, the demonstrators outperformed the observers in ten of the eleven topic areas. The greatest disparity between presenters and observers occurred during the demonstrations on wave properties where the demonstrators exceeded the observers by 14.5 percentage points. For the fluid mechanics demonstrations, the demonstrators and observers are essentially equal, and during the demonstrations on rotational motion, the observers outperformed the presenters by 2.5 percentage points. The presenters outperformed the observers an average of 6.5 percentage points.

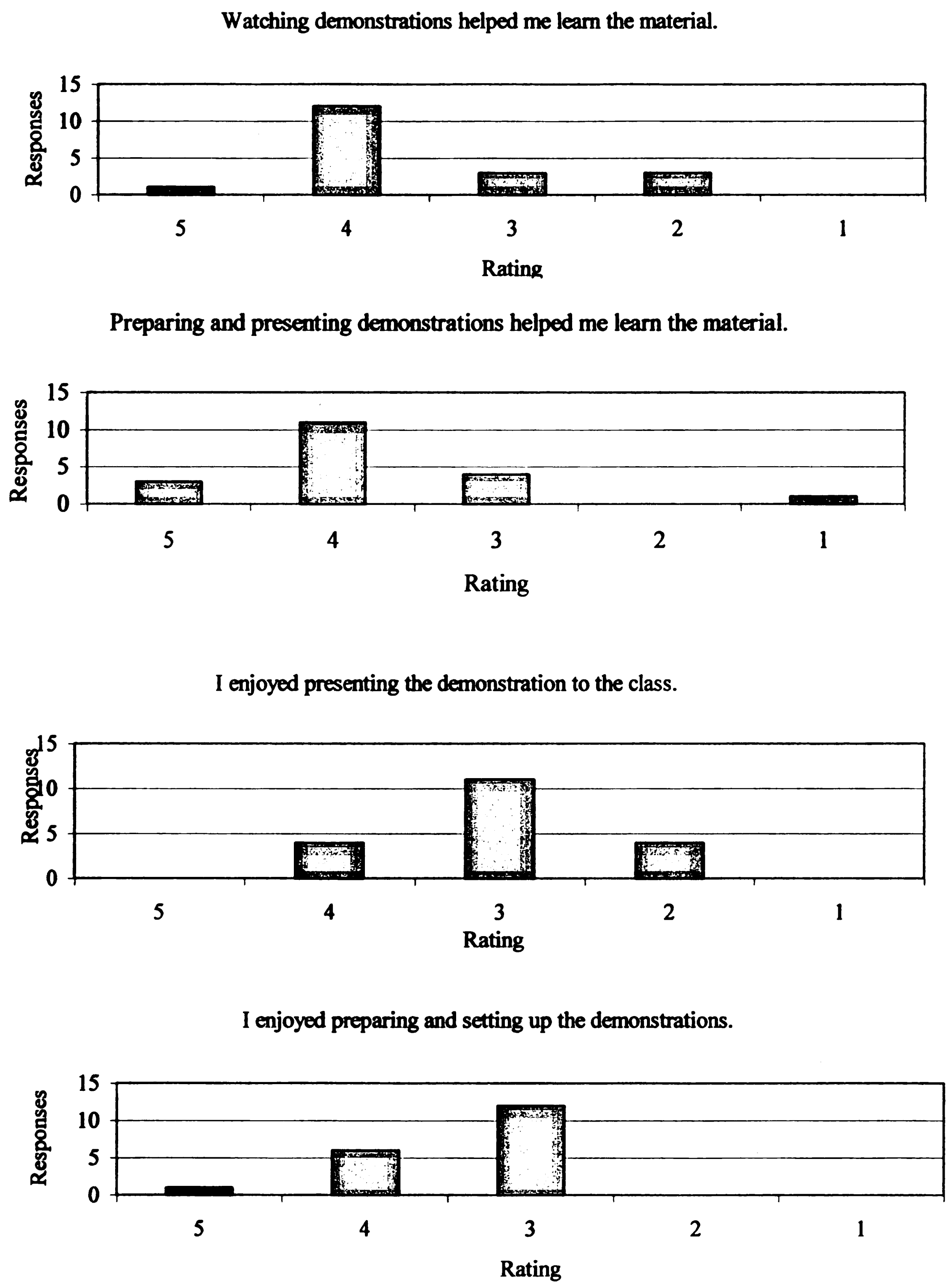
Figure 3: Comparison of Posttest Scores for Presenters and Observers



The presenters perform modestly better than the observers, but the difference is not overwhelming. The relevance comes from the consistency at which the demonstrators outperformed the observers. This indicates that preparing and performing the demonstration consistently may give the presenters a slight advantage over observers. In the second semester, the requirements of the observers were changed in an attempt to improve observer scores. There is little difference between the scores of the first semester and the second semester to indicate that the change was effective.

The final evaluation instrument was a student opinion survey, which is found in Appendix A-III. The survey asked students to rank a statement with a number ranging

Figure 4: Responses to the Student Opinion Survey



from one to five. Five indicated that the student strongly agreed with the statement, one indicated that the student strongly disagreed with the statement, and three indicated that the student neither agreed nor disagreed with the statement. The responses to four selected questions are graphically illustrated in Figure 4. The responses indicate that students feel that the demonstrations did help them learn. They agreed with this statement both as observers and as presenters with a four being the most common response to each question.

Survey questions were also asked about how the students enjoyed preparing and presenting the demonstrations. For each of these questions, the most common response was a three. This means that the students neither liked nor disliked it. The responses were slightly more positive for preparing the demonstrations than for presenting the demonstrations to the class. The student surveys do reflect a healthy attitude towards the project. The students could see the benefits of what they were doing, even if presenting the demonstrations was not a favorite thing to do.

IV. Discussion

In the Introduction to this paper anecdotal evidence was presented that indicated demonstrations are an important tool for teaching science. An evaluation of the physics curriculum at Mio AuSable High School showed few demonstrations being done by the instructor due to a lack of time for their preparations. It was the desire of the instructor that the number of demonstrations be increased and structured in such a way that they could be repeated every year. During the summer of 2001, a set of demonstrations was developed, during a designated research time at Michigan State University, that could be prepared and presented by groups of students to the rest of the physics class. The purpose of this project was to evaluate the effectiveness of these student-led demonstrations.

The results show the demonstrations to be quite effective. Students performed an average of 62.5 percentage points higher on the posttests than on the pretests. Of course the gains cannot be exclusively attributed to the demonstrations. The students were in a high school physics class and most of the topics covered in the demonstrations were covered in other ways as well. There was not a group of similar students in a similar high school physics class, but not seeing student-led demonstrations, to serve as a control group. However, the students did show significant improvement that at least in part was related to the demonstrations.

In this project, the students did the work of setting up and presenting the demonstrations. The implementation section of this paper raised the question of whether it was fair to the students to require them to make these preparations. It could be asked what did the students gain from the extra effort. There were two benefits to the students who performed the demonstrations. The first is that physics demonstrations were performed in their physics class. Few demonstrations were performed in the past due to lack of preparation time, and this was not likely to change. Without this approach, there would have likely been very few demonstrations performed during the 2001-2002 school year. Since the evidence indicates that demonstrations increase the students' ability to answer questions on the topics, the effort improves their experience and can therefore be justified.

A second benefit is the students performing demonstrations generally performed better on the posttest than did the observers. If the classroom teacher performed all of the demonstrations, no students would get this added benefit. Unlike the total gains of the class over the pretest, the improved performance of the presenters over the observers can confidently be attributed to their preparing and performing the demonstrations. The two groups had essentially the same experience in the classroom. They sat through the same lectures, completed the same assignments and conducted the same laboratory experiments. The only part that was different between the two groups was the demonstrations. One group prepared and presented them, the other simply observed. Preparing and performing demonstrations is beneficial to students and is a legitimate method of having demonstrations presented to a class.

The greatest drawback to the student-led demonstrations was their timing. The demonstrations were usually performed near the end of the time covering a topic, shortly before the test. This proved necessary because it took the student-groups time to master the material and prepare the demonstrations. Sometimes the students needed to try the procedure several times to be able to perform the demonstrations successfully. The demonstrations may have been more effective earlier in the unit when the topics were first introduced to the students, but that was not possible.

At the beginning of the second semester a change was made in the procedure followed by the students observing the demonstrations. The observers were given a response form to fill out during the demonstration. The data collected for the second semester does not support any conclusions about the effectiveness of this change. The data is similar between the two semesters, but as the topics covered were different, comparing the two semesters is not conclusive. Anecdotally, the instructor noted the observers to be more engaged during the second semester when immediate feedback was required of them. As the demonstrations continue in future years, it is the intention of the instructor to require immediate feedback from the students during each semester.

In the Introduction to this paper, it is stated that a prime reason that demonstrations are not done in high school physics classes is the time needed for them to be set up. It is worth noting that there was considerable time spent by the teacher getting the demonstrations prepared to a point that the students could do them successfully. Would it have been more time effective for the teacher to have prepared and presented the demonstrations himself? The answer is no, the student-led demonstrations seemed a better use of the teacher's time. Most of the work required of the teacher was completed during the summer when preparation time is more abundant. During the school year, very little of the teacher's time was needed to help the students prepare. Furthermore, the majority of the teacher's preparation time in the summer was spent creating written directions and background information for students. This is work that will not need to be repeated in future years. The time investment spent in the summer of 2001 can result in physics demonstrations performed for many years in the physics class with little time required of the teacher.

Using students to perform physics demonstrations may not be as time effective for larger schools. Based on its athletic team divisions, Mio AuSable High School is smaller than almost 75% of the schools in the state of Michigan. In a large school, a physics teacher would likely have several sections of the class. Teacher time spent preparing a demonstration could be justified by the fact that the demonstration would be shown several times throughout the day. Furthermore, in a large school, using students to perform demonstrations would mean that at any one time several groups of students would be preparing a demonstration. This would require more equipment and more teacher time assisting students. However, for a small school with one section of physics, student-led demonstrations are a bargain. They result in a big return on a modest time investment.

The most significant change in future years will be to the number of demonstrations done by the class. It was stated earlier that the 2001-2002 physics class was exceptionally large for Mio AuSable High School. Even if group size is reduced, there will still be fewer groups presenting demonstrations. This will allow the instructor to be more selective about the demonstrations assigned to the students.

In future years it would be worth noting if some demonstrations consistently provide richer experiences for the presenters. During this study, the groups that presented the topics of force components, wave properties and reflection performed over ten percentage points higher on the posttest than did the observers. In future years, the scores could be compiled in the same way to see if these topics are particularly advantageous or if the improvement is caused by the abilities of the students. Conversely, the group that demonstrated the topic of rotational motion did not perform better than the observers on the posttest. It would be worth noting if this trend continues as well.

Demonstrations can be a powerful tool in teaching science. A demonstration can take an abstract idea and make it easy for students to visualize. Demonstrations require little class time and relatively little equipment to perform. The great limitation to performing many demonstrations is the time required for their preparation. Having students prepare and present demonstrations is an effective way to include more demonstrations. It benefits all of the students, the presenters and the observers alike.

Appendix A: Evaluation Tools

Appendix A-I: Semester One Pretest/Posttest Questions with Evaluation Rubrics

Subject: Fluid Mechanics

A stream of air is flowing through the tube below.

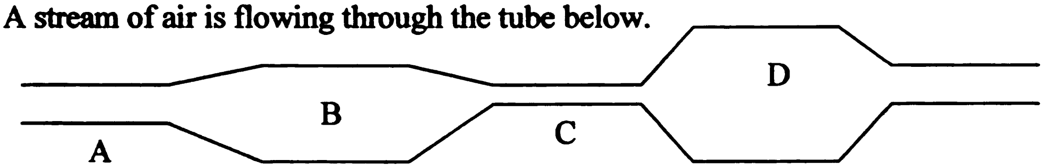


Figure 5: Venturi's Principle Question

1. For the tube above, which section of the tube has the air traveling the fastest? (Explain.)

Table 1: Rubric for Evaluation of Fluid Mechanics Question One

1 point	Response identifies the correct region.
2 points	Response correctly relates diameter of tube to speed

2. For the tube above, in which section is the air exerting the most pressure on the sides of the tube? (Explain.)

Table 2: Rubric for Evaluation of Fluid Mechanics Question Two

1 point	Response identifies the correct region.
2 points	Response relates speed to pressure

3. When you drink through a straw, what forces the liquid up?

Table 3: Rubric for Evaluation of Fluid Mechanics Question Three

1 point	Response states that liquids move from areas of high pressure to areas of low pressure
2 points	Response includes the identification of the weight of the air as the source of the pressure.

4. Using density, explain why some objects sink and some objects float.

Table 4: Rubric for Evaluation of Fluid Mechanics Question Four

1 point	Response is a partial description of the answer described below.
2 points	Response states that objects with a lower density float on fluids with a higher density

5. Using Archimedes' Principle, explain why some objects sink and some objects float.

Table 5: Rubric for Evaluation of Fluid Mechanics Question Five

1 point	Response includes a description of a buoyant force being equal to the weight of the displaced fluid
2 points	Response includes an explanation that the buoyant force equals the weight of the object for the object to float.

Subject: Thermal Energy

1. You have a piece of metal with a hole in it. If the metal is heated, will the hole get bigger get smaller or stay the same size? Explain your answer.

Table 6: Rubric for Evaluation of Thermal Energy Question One

1 point	Response states that the hole increases in size
2 points	Response includes the fact that particles move faster and increase their separation distance.

2. In an experiment, 50 g of copper and 50 g of water are each heated to 90°C. Which of the two contains more energy? Explain why you chose the one that you did using the term specific heat in your explanation.

Table 7: Rubric for Evaluation of Thermal Energy Question Two

1 point	Response states that the water has more heat energy
2 points	Response correctly relates the above to specific heat

3. You are heating a pan of water on the stove; does the pan get hotter than the water, stay cooler than the water or stay the same temperature as the water? Explain your answer.

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Table 8: Rubric for Evaluation of Thermal Energy Question Three

1 point	Response states that the two will have the same temperature.
2 points	Explanation relates the idea that objects in contact gain or lose energy until each has the same temperature.

Subject: Wave Properties

1. It is a property of waves that they travel in a straight line, if this is true why do waves that start from a point travel as circles?

Table 9: Rubric for Evaluation of Wave Properties Question One

1 point	A partial explanation is given.
2 points	Response states that the wave travels in a straight line in every direction.

2. What is the relationship between a wave's frequency and its wavelength?

Table 10: Rubric for Evaluation of Wave Properties Question Two

1 point	A partial explanation is given.
2 points	Response identifies the relationship as inverse.

3. What determines the speed of a wave?

Table 11: Rubric for Evaluation of Wave Properties Question Three

1 point	Response identifies the medium as the determining factor.

4. What is the difference between the properties of reflection, refraction and diffraction?

Table 12: Rubric for Evaluation of Wave Properties Question Four

1 point	Response includes one property correctly described.
2 points	Response includes two properties correctly described.
3 points	Response includes all three properties correctly identified.

Topic: Sound

1. Describe what happens to an object to cause it to resonate.

Table 13: Rubric for Evaluation of Sound Question One

1 point	A partial explanation is given.
2 points	Response includes a description of a standing sound wave.

2. How does sound waves vibrate in a tube closed at one end (such as a pop bottle) compared to a tube open at both ends (such as a trombone)?

Table 14: Rubric for Evaluation of Sound Question Two

1 point	A partial explanation is given.
2 points	Response distinguishes between the positions of nodes and antinodes for an open and closed tube.

3. Describe what happens to sound waves to produce a beat.

Table 15: Rubric for Evaluation of Sound Question Three

1 point	A partial explanation is given.
2 points	Response identifies the constructive and destructive interference that takes place to produce a beat.

Topic: Reflection of Light

1. State the law of reflection as it applies to mirrors.

Table 16: Rubric for Evaluation of Reflection Question One

1 point	Response states that the angle of incidence is equal to the angle of reflection

2. Look at the drawing below of a laser hitting a curved mirror. The "C" stands for the center of curvature and "F" stands for the focal point. For each diagram, draw in the ray that is reflected off of the surface of the mirror.

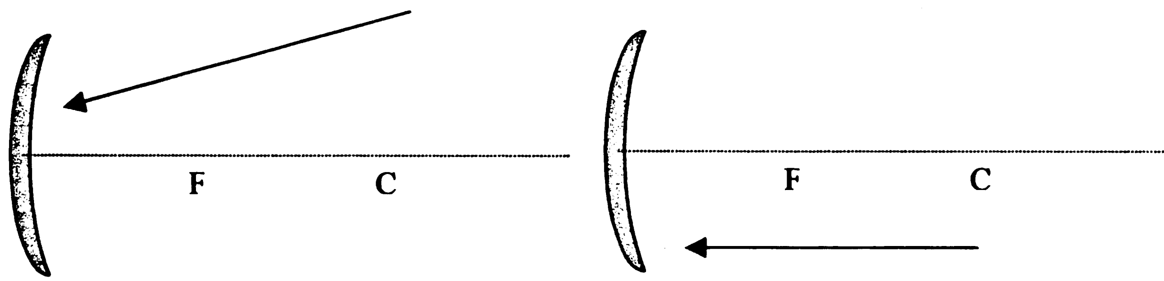


Figure 6: Reflection of a Concave Mirror Question

Explain why you gave the reflected ray the path that you did.

Table 17: Rubric for Evaluation of Reflection Question Two

1-2 points	A partial explanation is given.
3 points	Each ray is given the correct path. Response uses a line through the center for measuring angles.

3. When a laser reflects off of a standard mirror, two rays are often seen leaving the mirror. The two rays run parallel to each other. Explain what causes the one ray to become two rays.

Table 18: Rubric for Evaluation of Reflection Question Three

1 point	A partial explanation is given.
2 points	Response identifies the ray reflecting off the glass and off the silver.

Topic: Electrostatics

1. What is the Basic Law of Electrostatics?

Table 19: Rubric for Evaluation of Electrostatics Question One

1 point	A partial explanation is given.
2 points	Response states that opposite charges attract and like charges repel.

2. What is the difference between charging an object by conduction and charging it by induction?

Table 20: Rubric for Evaluation of Electrostatics Question Two

1 point	A partial explanation is given.
2 points	Response identifies that conduction requires contact, while induction only requires close proximity. The response also includes a description of conduction charging the second object with a like charge, while induction produces an opposite charge.

3. How does a lightning rod attract lightning to it?

Table 21: Rubric for Evaluation of Electrostatics Question Three

1 point	A partial explanation is given.
2 points	Response describes the electric field near a potential conductor as being stronger than the surrounding area.

Appendix A-II: Semester Two Pretest/Posttest Questions with Evaluation Rubrics

Topic: DC Circuits

1. Describe the property of resistance.

Table 22: Rubric for Evaluation of DC Circuits Question One

1 point	A partial explanation is given.
2 points	Response describes resistance reducing the flow of current through a material.

2. Describe a way to connect two resistors together in a circuit so that less current is able to flow through the circuit.

Table 23: Rubric for Evaluation of DC Circuits Question Two

1 point	A partial explanation is given.
2 points	Response describes a series circuit and refers to it by name

3. Describe a way to connect two resistors together in a circuit so that more current is able to flow through the circuit.

Table 24: Rubric for Evaluation of DC Circuits Question Three

1 point	A partial explanation is given.
2 points	Response describes a parallel circuit and refers to it by name.

Topic: Newton's Laws

1. Describe Newton's First Law, Inertia.

Table 25: Rubric for Evaluation of Newton's Laws Question One

1 point	A partial explanation is given.
2 points	Response correctly describes inertia.

2. Describe Newton's third law.

Table 26: Rubric for Evaluation of Newton's Laws Question Two

1 point	A partial explanation is given.
2 points	Response correctly describes equal and opposite forces.

Topic: Force Components

1. Imagine the car below sitting on an inclined plane. The wheels have been blocked to keep it from rolling down. Use arrows to show all forces acting on the car.

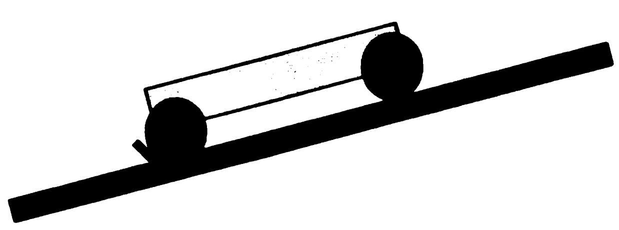


Figure 7: Force Components on an Inclined Plane Question

Table 27: Rubric for Evaluation of Force Components Question One

1 point	Most forces are present but some are missing.
2 points	Response correctly shows all forces

2. For each force labeled in number 1, describe the relationship between that force and the force of gravity.

Table 28: Rubric for Evaluation of Force Components Question Two

1 point	A partial explanation is given.
2 points	Response correctly relates each force to gravity.

Topic: Circular Motion

1. Two objects are moving along circular paths. How is it possible for them to have the same rotational speed but different tangential speeds?

Table 29: Rubric for Evaluation of Circular Motion Question One

1 point	A partial explanation is given.
2 points	Response correctly identifies the paths as having different radii.

2. What is the critical velocity of an object on a circular path? What is the main factor that affects the critical velocity?

Table 30: Rubric for Evaluation of Circular Motion Question Two

1 point	A partial explanation is given.
2 points	Response correctly describes critical velocity and identifies the radius of the path as the main factor.

Topic: Rotational Motion

1. What two quantities are related to the torque on an object?

Table 31: Rubric for Evaluation of Rotational Motion Question One

1 point	A partial explanation is given.
2 points	Response correctly identifies both force and length.

2. What two quantities must be zero for an object to be in equilibrium?

Table 32: Rubric for Evaluation of Rotational Motion Question Two

1 point	A partial explanation is given.
2 points	Response correctly identifies both net force and net torque.

Appendix A-III: Questions Represented on the Semester One Exam

1. Using Archimedes' Principle, explain why some objects sink and some objects float.

Table 33: Rubric for Evaluation of Semester One Exam Question One

1 point	Response includes a description of a buoyant force being equal to the weight of the displaced fluid
2 points	Response includes an explanation that the buoyant force equals the weight of the object for the object to float.

2. In an experiment, 50 g of copper and 50 g of water are each heated to 90°C. Which of the two contains more energy? Explain why you chose the one that you did using the term specific heat in your explanation.

Table 34: Rubric for Evaluation of Semester One Exam Question Two

1 point	Response states that the water has more heat energy
2 points	Response correctly relates the above to specific heat

3. What is the relationship between a wave's frequency and its wavelength?

Table 35: Rubric for Evaluation of Semester One Exam Question Three

1 point	A partial explanation is given.
2 points	Response identifies the relationship as inverse.

4. What is the difference between the properties of reflection, refraction and diffraction?

Table 36: Rubric for Evaluation of Semester One Exam Question Three

1 point	Response includes one property correctly described.
2 points	Response includes two properties correctly described.
3 points	Response includes all three properties correctly identified.

Appendix A-IV: Example Homework Questions

Each topic area contains example homework questions given to the students using the LON-CAPA system described in the implementation portion of this paper. When the student submits responses via the internet, the response will be either correct or incorrect for the entire group of questions. If any one response is incorrect, the student will be told incorrect, without any feedback about the number or identity of the incorrect responses.

Topic: Fluid Forces

Label each of the following statements as true or false.

Absolute pressure is always less than or equal to gauge pressure.

In a hydraulic device, the pressure is equal everywhere throughout the device.

A buoyant force acts in a downward direction.

The amount of pressure is directly related to the size of the area it acts upon.

When an object floats, the buoyant force is equal to the force of gravity.

Some fluids do not have a definite volume.

Topic: Thermal Energy

Most materials increase in size when their temperature increases.

When water is heated in a container, the container gets hotter than the water.

As water boils it continues to get hotter.

When an object is heated, the particles that make it up move faster.

When a solid with a hole in it is heated, the hole gets smaller.

All materials require the same amount of energy for a temperature change.

If 100g of water and 100g of lead are each at 90 °C, the lead contains more heat energy.

The quantity known as specific heat relates energy to both volume change and mass.

Topic: Wave Properties

Identify each statement as true or false.

When a straight wave pases through a small opening, it produces a small straight wave.

A wave will always reflect off of a barrier at the same angle that it hits.

As the frequency of a wave increases, its wavelength decreases.

As a wave changes media its speed changes.

The speed of a wave is determined by its medium.

Two waves traveling through the same medium meet, they will combine to form a new wave.

During diffraction, a wave bends because it hits the edge of a barrier.

A straight wave heads into a curved surface. It will reflect into a central point.

Unless it is disturbed each point on a wave will travel along either a straight or curved path.

Refraction is the bending of a wave because its speed changes.

Appendix A-V: Student Opinion Survey

Opinion Survey on Student Demonstrations

Please read each of the statements below and rate it 1-5 based on the following scale.

5. I strongly agree with the statement.

4. I agree with the statement.

3. I neither agree nor disagree with the statement.

2. I disagree with the statement.

1. I strongly disagree with the statement.

_____ Watching the classroom demonstrations helped me learn the material.

_____ I enjoyed watching other students perform demonstrations.

_____ Preparing and presenting demonstrations helped me learn the material.

_____ The demonstrations that my group did went well.

_____ Working in groups is a good way to prepare demonstrations.

_____ I enjoyed preparing and setting up the demonstrations.

_____ I enjoyed presenting the demonstrations to the class.

Appendix B: Physics Demonstrations

Appendix B-I: Fluid Mechanics Demonstrations

Part 1: Water Bottle Boats – Archimedes' Principle

This demonstration will show that when a boat floats, it displaces enough liquid to equal its weight.

Collect the following Materials:

3 large graduated cylinders	1500 ml water (tap water is ok)
3 20-24 oz drink bottles	1500 ml alcohol
sand	1500 ml glycerine
3 200 g masses	food coloring

1. Cut the tops off of the drink bottles.
2. Add enough sand to the bottles so that each has a total mass of 100 g.
3. Add a different color of food coloring to each of the liquids and place each in a graduated cylinder.

The three graduated cylinders are placed in an observable location. One has 1500 ml of water, the second has 1500 ml of alcohol and the third has 1500 ml of glycerin. Each has been colored a different color with the food coloring. The presenter places a boat of mass 100 g into each liquid. It is observed that the boat in the water displaces 100 ml of water, the boat in the glycerin displaces less and the boat in the alcohol displaces more.

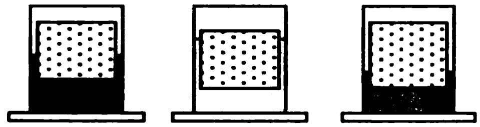


Figure 8: Equal Masses in Different Liquids

A 200 g mass is added to each boat. It is observed that in each cylinder, the boat lowers into the liquid and the liquid level rises. The liquid's density determines the amount that needs to be displaced. The presenter will then show how to use the mass of the boat and the volume of the displaced water to calculate the density of each liquid.

Explanation:

Why does an object in a fluid seem to be lighter? When an object goes into a fluid, it must push the fluid out of the way. We say that the fluid is displaced.

Newton's Third Law says that for every force there is an equal and opposite force. This means when the object pushes on the fluid, the fluid pushes back on the object. This is called a buoyant force. The buoyant force works opposite to the force of gravity and lifts the object.

Archimedes' Principle describes the strength of the buoyant force on a object. It states:

The buoyant force on an object is equal to the weight of the fluid that it displaces.

An object floats when it displaces enough of a fluid to equal its weight. For example, when a boat is put into the water, it sinks into the water until the weight of the water being displaced is equal to the weight of the boat.

When you get into the boat, it sinks deeper into the water. It displaces enough water to equal your weight and the weight of the boat. If the boat is carrying too much weight, it cannot displace enough water and it sinks.

Whether an object floats or sinks in a fluid depends on its mass as it compares to its volume. The ratio of an object's mass to its volume is called its density.

Part 2: Pressure Fountain

This demonstration illustrates the concept that fluids move from areas of high pressure to areas of low pressure.

Materials

1 1000ml erlenmeyer flask with outlet port

1 #8 1 hole rubber stopper

30-40 cm glass tubing

2 1000 ml beakers

30-40 cm of latex tubing

food coloring

1 ring stand with iron ring

1 hose clam

1. Construct the device as shown in the diagram at the right.

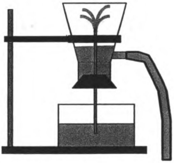


Figure 9: Pressure Fountain

2. Place 300 ml of water in the flask, stopper the flask and invert. Place the glass tube under the water in the lower beaker. Have the latex hose run into the second beaker.

<u>How does it work?</u>

Fluids move from areas of high pressure to areas of low pressure. When the flask is inverted, water runs out of the latex tube. As the water level lowers, this creates a larger volume for the air in the flask. According to Boyle's Law, the larger volume causes a lower air pressure in the flask.

The water in the lower beaker has the weight of the atmosphere resting on it and is therefore at a higher pressure than the air in the flask. The higher pressure pushes the water up into the flask. This process is in a cycle and everything happens at the same time. If the intake tube is plugged, no water is released from the outlet hose.

<u>The Demonstration:</u>

Begin with an analogy of drinking through a straw. Ask the question, "Could we drink through a straw if there was no air?" Have the class consider an astronaut on the moon. He has a large tank of water with an open top. A straw runs from the tank, through a sealed opening in his helmet and to his mouth. Can he drink from the tank? If he could, there would be no point in the demonstration so the answer must be "no".

Demonstrate the fountain and describe how it works. Now describe how a straw works. Explain that as you remove the air from your mouth, the air pressure on the liquid pushes it up into your mouth. If there is no difference in pressure, the liquid does not move.

Ask the class what will happen if the outlet hose is placed in the intake tank. The fountain stops because there is no difference in pressure.

Part 3: Floating Balls

This demonstration uses Bernoulli's Principle to make a ball float in air.

Materials:

Air source	Ping pong ball
Various sizes of Styrofoam balls	Funnel

The Demonstration:

Attach the funnel to the air source. Place the ping-pong ball in funnel. Ask the class to predict what will happen when the air source is turned on. Demonstrate that when the air is turned on, the ball does not leave the funnel. Further demonstrate that the funnel can be inverted and the ping-pong ball remains in the funnel.

Set up the air source to produce a vertical stream. Place the balls in the stream so that they float in the stream. Describe how the moving flow of air is able to support the ball.

How does it work?

Bernoulli's Principle states that a moving stream of fluid exerts less pressure than the surrounding fluid. In the first case, the air moves in a stream around the ball.

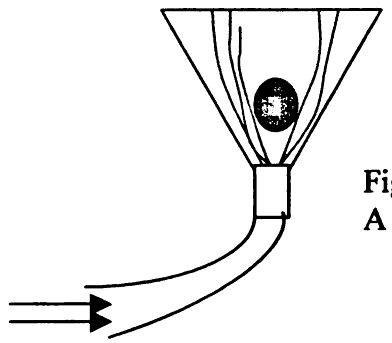


Figure 10: Air Flow Around A Ball in a Funnel

The moving streams are at a lower pressure than the surrounding area. The higher pressure surrounding the ball pushes the ball into the funnel to keep it from falling out.

This principle will work whether or not the funnel is present. In the second demo, the ball can be supported on the stream. The slower moving air on the outside exerts pressure on the ball to keep it in the stream.

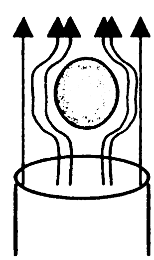


Figure 11: Air Flow Around a Ball in an Airstream

Credits:

Parts 2 & 3: Doherty, Paul and Rathjen, Don. 1996 The Spinning Blackboard and Other Dynamic Experiments on Force and Motion. John Wiley and Sons. 3.

Part: Walpole, Brenda. 1988. 175 Science Experiments to Amuse and Amaze Your Friends. Random House. 33.

Appendix B-II: A Collection of Heat Demonstrations

Materials:

Ball and ring set	Water
Balloon	2 150 ml beaker
Lab Burner	1 pan
Paraffin wax	2 thermometers
Set of metal samples (Cu, Fe, Al, Zn)	Balance
Hot plate	Ring stand and clamps
Beaker	Gooseneck Camera with TV
Tongs	Paper Cup
Lead shot	Pipestem Triangle

Part I: A Hole in a Solid

Pose the following problem to the class. "You have a piece of metal with a hole in it. If the metal is heated, does the hole get bigger or smaller?"

Allow for discussion and let each student predict the correct answer. Get out the ball and ring model. Show that the ball does not pass through the ring at room temperature. Heat the ring in the lab burner. Show the class that the ball will now fit through it.

This happens because of the motion of the atoms in the metal ring. As the temperature increase, the atoms move faster and increase the space between them. This makes the entire metal expand, including the hole. This can be shown by drawing several dots and a circle on a deflated balloon. When the balloon is inflated, it is noted that the dots are farther apart and the circle is bigger.

Part II: Specific Heats of Lead and Water

Pose the following problem to the class.

You have two beakers. One contains 100g of solid lead the other contains 100g of water. Each is heated to the same temperature. Which will better be able to melt wax that is put in it?

Allow students to voice their opinions. Let each student predict the answer. Set up the equipment as shown below. Place 100g of lead in one beaker and 100 g of water in the other. Heat the larger beaker for the hot water bath on the hot plate and monitor the temperatures of the two smaller beakers. When the temperature of the small beaker is between 80-100 °C, remove the beakers from the water bath and place them on the table. Remove the water first. Have the gooseneck camera set up to show the activity in the small beakers. Place a small piece of wax in each beaker. Note that the one in the water melts quickly and the one in the lead hardly melts at all. Most students will usually predict the lead, but the specific heat of the water is much greater than the lead. This means that for the same mass at the same temperature, the water

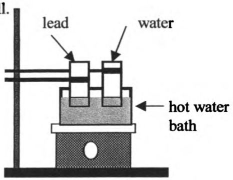


Figure 12:Heat of Lead and Water

contains more heat energy. People think of metals as "hotter". This is because it has such a low specific heat that its temperature will increase significantly with a small amount of energy. A metal can have a very high temperature and still contain less energy than a cooler mass of water.

Part III: The Great Metal Race

Before the demonstration, you will need to make a wax pancake. Melt some paraffin wax and pour it out on the lab bench. You want it to cover a large area but not very thick. Make sure that it is cool before you begin. Suspend the wax pancake over the lab table.

Set up a hot water bath. Connect the four metal samples together and place them in the bath. If the samples have hooks on them they can be connected by hanging them on a bent coat hanger. If there are not hooks, they can be connected with a string. Make sure that this is set up so that the metals each have some space between them. Explain to the class that you will set the masses on the wax and they will melt through. Ask the students to predict the order that they will fall through. Remove the masses from the bath and place them on the wax pancake. Have the camera in position to observe the masses falling through the wax.

After the demonstration, you should note that the order is the same as the order of their the specific heats. At the same temperature, the metals with the higher specific heats contain more heat energy and are better able to melt through the wax.

<u>Part IV: Boiling Water in a Paper Cup</u>

This classic demonstration shows that a set of objects in contact with each other heat as one object. The paper cup is placed on a pipestem triangle above a lab burner. The water is heated to boiling without the cup catching on fire. This demonstration takes a few minutes and it is best to set it up and let the water heat while the other demonstrations are going on.

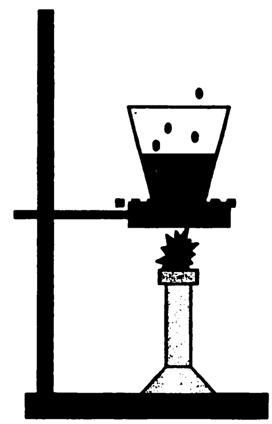


Figure 13: Boiling Water in a Paper Cup

So why doesn't the cup catch on fire? This is the question that makes this demo interesting. Heat transfers from high temperature to low temperature. As the cup heats up it transfers the heat energy to the water. The water boils at 100°C so the cup never gets above that temperature. The paper will only burn if the temperature gets above its flash point. It never gets there because the water absorbs the heat. Even once the water is boiling the cup still does not burn. The water is still absorbing the heat energy. It cause the water molecules to move faster and change from the liquid state to the vapor state.

Credits for Part 2: Heimler, Charles H. and Paul W. Zitzewitz. 1989. Focus On Physical Science Teachers Edition. Merrill Publishing. 113.

Appendix B-III: Ye Olde Ripple Tank Demo

This demonstration uses a ripple tank to show a variety of wave properties. Most of the equipment listed below can be found in a standard physics lab.

Materials:

Ripple Tank

Wave Generator

Light Source

Tall Ring Stand

Goose Neck Camera and TV

Glass Blocks

Hose

Drain Bucket

Strobe Light

Plain White Paper

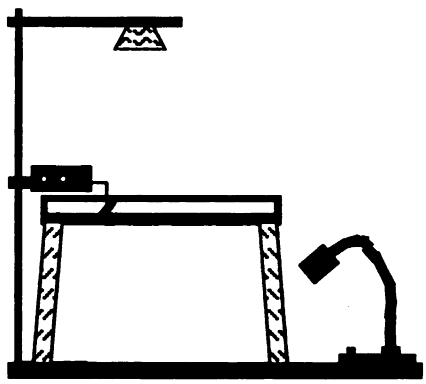


Figure 14: Ripple Tank

Set up the ripple tank on a level surface. Adjust the tank so that the water has a uniform depth. Set up the gooseneck camera so that the observation surface is seen on the TV screen. Pass out paper to each student.

Have the students fold the paper so that there are six squares on a side. Lead the students through each demonstration and have them make observations for each. In any step the strobe light can be used to make the wave appear to stand still for easier observations.

Part 1: Rectilinear Propagation

Use the wave generator to make several straight waves. Point out to the students that the waves travel in straight lines and this property is called rectilinear propagation.

Part 2: Rectilinear Propagation from a Point Source

Use a pencil to create a wave in the center of the tank. Note that the wave travels as a circle away from the point. The question then is why does this wave not travel in a straight line. The answer is that it does. Each point along the wave crest travels straight away from the source creating a circle.

Part 3: The Relationship Between Frequency and Wavelength.

Use the wave generator to change the frequency of the wave. Notice that as the frequency increases, the wavelength decreases. The speed of a wave is determined by its medium. If the frequency increases, there are many waves traveling at the same speed, so they get closer together.

Part 4: Reflection of a Straight Wave from a Straight Barrier

Make a straight barrier in the tank out of two glass blocks. Align it so that the waves strike the barrier at an angle. Send several straight waves toward the wall. Notice that the angle of incidence is equal to the angle of reflection. You can verify this by changing the angle of the wall. Notice that the angle of reflection also changes.

Part 5: Reflection of a Curved Wave From a Straight Barrier

Leave the glass blocks in the tank. Make a wave from a point source as in part 2. Notice how the shape of the wave inverts itself after it hits the barrier. This is because the parts of the wave reflect in the order that they hit. The lead edge hits first and makes it invert as the rest of the wave reflects.

Part 6: Straight Waves from a Curved Barrier

Replace the glass blocks with a thick piece of garden hose. Bend the hose to form a curved barrier. Allow several straight waves to hit the barrier. Note the point at which the waves converge. This point is referred to as the focal point.

Part 7: Diffraction of a Wave on a Corner

Remove one of the blocks. Adjust the one in the tank so that its edges are clearly seen. Start the wave generator and note the curving of a wave as it passes the edge of the block. The curving is caused by the slowing of the wave near the edge of the block. The speed of the wave is determined by the medium. Although the wave is still traveling through water, the friction between the water and the block does change its characteristics.

Part 8: <u>Diffraction Through an Opening</u>

Place the second glass block back in the tank so that there is a small opening between the two blocks. Turn on the wave generator and notice the curved shape of the wave leaving the opening. The wave diffracts on each edge around the opening and produces a curve.

Part 9: <u>Refraction of a Wave</u>

Lay one of the flat blocks flat on the bottom of the tank. Adjust the water level in the tank so that there is only a small layer of water over the top of it. Turn on the wave generator. Notice the bending of the wave over the block. This bending is caused by a change in speed of the wave.

Part 10: <u>Interference of a Wave</u>

Change the straight wave source for two point sources. Turn on the wave generator and notice the pattern that forms. Where a crest meets a crest, a larger wave results. This is called constructive interference. Where a crest meats a trough, a smaller wave results. This is called destructive interference. You should be able to see strips of destructive interference called nodes stretching across the tank.

Credits:

Trinklein, Frederick E. 1990. Modern Physics Exercises and Laboratory Experiments. Holt, Rinehart and Winston. 235.

Appendix B-IV: Resonance: We Got the Beat

This is a collection of demonstrations on the principle of resonance.

Materials:

Two ring stands with cross bar
String
3 200 g masses
tin can
balloon
laser
small plastic mirror
sound source (a signal generator or trombone)
Tuning forks mounted on resonance boxes
Tuning forks of various frequencies
Various lengths of pvc pipe

Part 1: A Coupled Pendulum

Two pendulums of about the same length are hung from a cross string. One is started causing the other to start. It is observed that the motion of each pendulum starts and stops at a regular interval.

As the first pendulum starts swinging, it pulls on the second; this starts the next one moving. This continues, with the first giving energy to the second on each swing. Once the first pendulum stops, the second one begins to pull on the first. And the cycle continues.

This is an example of sympathetic resonance, one vibrating object setting up a vibration in the second. Resonance in sound waves works the same way. Sound waves set up air vibrating in a closed space.

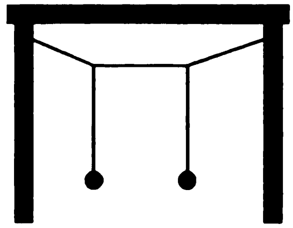


Figure 15: A Coupled Pendulum

Part 2: Resonating Tubes

Use the tuning forks to produce sounds of known frequency. Cut the pvc pipe to the correct lengths and demonstrate that the correct frequencies will cause the tubes to resonate. This is an example of sympathetic resonance, the tuning fork sets up the right wave in the tube and it resonates. This can further be illustrated with the tuning forks mounted on the resonance boxes. When the frequencies of the tuning forks match, starting one vibrating will cause the other to start vibrating.

During setup it is important to prepare lengths of tubes so that they will resonate at the correct frequency. From the desired frequency calculate the wavelength using the formula:

$$v = f\lambda$$

where v is the speed of sound in air, f is the frequency and λ is the wavelength.

The length of the tube is dependant on it being an open tube or a closed tube. For an open tube, the length is calculated using the equation:

$$\lambda = 2l$$

An open tube resonates with a standing wave that has an antinode at each end. Multiples of that frequency will also cause resonance. These multiple resonant frequencies are called harmonics.

Figure 16: Open Tube Harmonics

For a closed tube, the length can be calculated using the equation: λ=4l

A closed tube resonates with a standing wave that has an antinode at the open end and a node at the closed end. Only odd multiples of the fundamental frequency will cause resonance.

Figure 17: Close Tube Harmonics

The demonstrators must prepare several lengths of closed and open tubes before the demonstration.

Part 3: Seeing Sound Waves

One final demonstration on this point uses a can with a balloon stretched over the opening. A small light plastic mirror is glued to the balloon. A laser is shone on the mirror and reflected onto a screen.

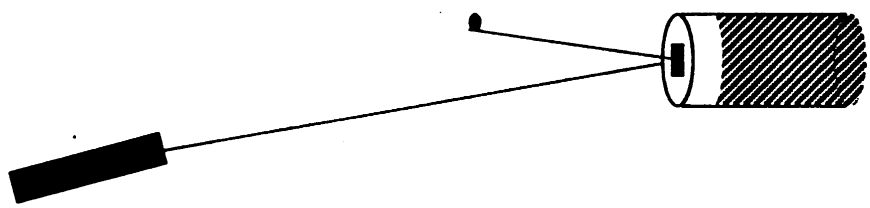


Figure 18: Sound Visualization Demonstration

Use the sound source to produce a sound. Change the frequency of the sound and observe the light. When the resonant frequency of the can is reached, the balloon will vibrate and a pattern will show on the screen. With the right equipment, various harmonics of the tube can also be shown.

Resonance will only occur when the frequency is right. Returning to the coupled pendulum, it can be shown that if the lengths of string are very different, then the sympathetic vibration will not occur. It can also be shown on the tuning fork boxes, when the frequencies are not close the second box stays silent.

Part 4: Beats

When sound waves that have close frequencies combine together they produce audible swells and lows. These swells are called beats. This was already shown with the coupled pendulum. It can also be shown with the tuning fork boxes. When the forks are adjusted so that their frequencies are only off by a few hertz, playing both shows this principle. The following diagram shows the interference pattern of the sound waves.

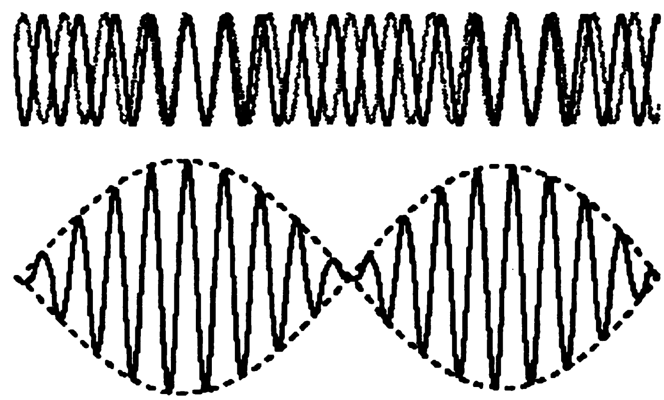


Figure 19: Beats

Credits: Part1: The Coupled Pendulum came from the book:

Doherty, Paul and Rathjen, Don; The Spinning Blackboard and Other Dynamic Experiments on Force and Motion; John Wiley and Sons, 1996.

The diagram in part 4 was taken from the web site:

http://hyperphysics.phy-astr.gsu.edu/hbase/sound/beat.html

Appendix B-V: The Laser Spirograph

A spirograph is a drawing toy that turns one circle inside of another to make interesting patterns. The same principle can be used to draw patterns with a laser.

Part I: Construction

Materials:

2 concave mirrors	1 screen
2 1.5-3.0 V motors	6 wires
1 3V DC source	2 25Ω rheostats
1 ring stand with cross bar	1 hot-glue gun
2 buret clamps	1 fog machine
1 laser	

1. Use the hot glue gun to connect the mirrors to the motors. The mirrors need to spin with the motors.

2. Assemble the materials as shown in the diagram below. The buret clamps are used to connect the motors to the ring stand.

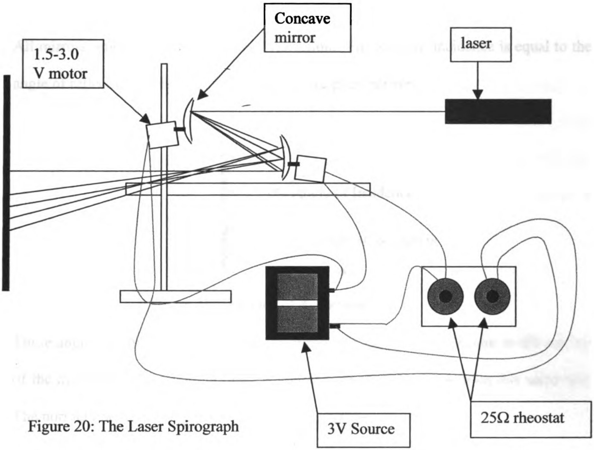


Figure 20: The Laser Spirograph

3. The most challenging part of construction is the alignment of the mirrors. The laser should hit the first mirror off center. Spin the first motor and you will notice that the reflected beam makes a circle. Adjust the position of the second mirror so that the entire circle falls on the mirror surface, but is not centered on the vertex of the mirror. Finally adjust the mirrors so that the rays reflecting off the second mirror hit the screen as desired.

Part II: How does it work?

All mirrors reflect based on the law of reflection. The angle of incidence is equal to the angle of reflection. This is easy to visualize on a plane mirror.

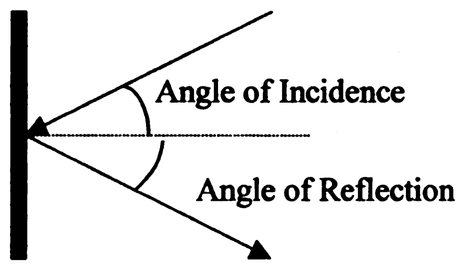


Figure 21: The Law of Reflection

These angles are measured against an imaginary line that is perpendicular to the surface of the mirror called the normal line. A concave mirror reflects based on this same law. The normal line for a concave mirror is the radius of the curve.

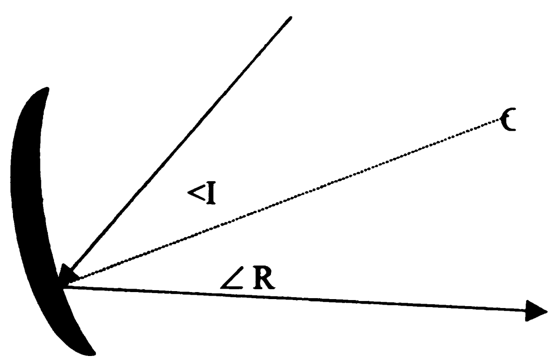


Figure 22: Reflection on a Concave Mirror

Like anything that spins, the mirror will "wobble" due to precession. This wobble changes the position of the normal line and therefore the position of the reflected beam. Because the wobble has a circular path, the reflected ray makes a circle. Because the wobbles of the two spinning mirrors are not in phase with each other, the spiral patterns result.

<u>When the mirrors are still, why do we see more than one point of light on the screen?</u>

Mirrors have a silver backing and a coating of glass on the front. The laser light reflects twice on the mirror, once on the glass and once on the silver. This creates two reflected rays. These two rays then reflect off the glass and the silver of the second mirror to produce the multiple dots.

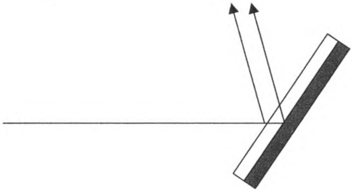


Figure 23: Reflection on Two Surfaces

<u>Why do we see a pattern and not just a point of light moving in a pattern?</u>

The answer to this says more about your eyes and less about the device. When you look at something, its image lingers for a moment. This is most noticed when you look at a bright light and then look away. You see the image after the fact. The image of the point of light lingers as the point of light moves. This creates the appearance of a pattern. At any moment, the ray of light is only at one point. If a picture of the pattern is taken, it will show an image that is incomplete. This is because the shutter speed of the camera is faster than the retention time in your eye and does not capture the entire image.

Part III: The Demonstration

Begin the demonstration by showing the laser light show. Turn on the motors and make various patterns on the screen by adjusting the speed of the motors. The pattern can also be affected by adjusting the spacing between the mirrors. This, however, can be difficult. The use of a fog machine can make the show more spectacular.

In the process of explaining, shine a laser at a plane mirror mounted on a magnet attached to the chalkboard to show the law of reflection. If the mirror is positioned so that the normal line is parallel to the ground, then a gravity protractor can be used to measure the angles of incidence and reflection. Change the position of the laser to show that changing the angle of incidence will cause an equal change in the angle of refraction. Use the fog machine to illuminate the beams.

Change the mirror to a concave mirror mounted so that the primary axis is parallel to the floor. Draw the primary axis and label the center of curvature. Shine the laser on the surface of the mirror from various angles to show that the law of reflection holds true for a curved mirror also. Remember that the normal line is a radius of the circle.

It is a common misconception that a ray reflected from a concave mirror passes through the focal point. This is only true if the ray is parallel to the primary axis.

Turn the laser spirograph back on and point out the wobble in the mirrors. Explain how the wobble creates a circular pattern and the second mirror changes the pattern. This can be illustrated by only running one mirror.

Appendix B-VI: The Great Ball of Death

(A Collection of Demonstrations Using a Van deGraaff Generator)

These demonstrations use a Van deGraaff generator to illustrate a number of points about electrostatics.

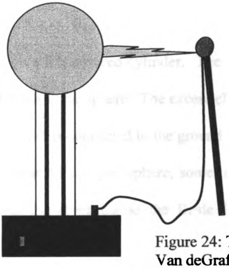


Figure 24: The Van deGraff Generator

Materials:

Van deGraaff generator

Discharge wand

Tin can

3 metal plates

Styrofoam board for insulation

5 aluminum pie pans

1 spring

string

tape

thin wire

aluminum foil

2 styrofoam balls, 4 cm diam.

1 stryrofoam ball, 15 cm diam.

Large erlenmeyer flask

1 metal coat hanger

2 small metal balls

1 plastic milk crate

2 long insulated wires with alligator clips

Part 1: <u>Discharge</u>

Plug in the Van deGraaff generator and turn it on. Hold the discharge wand near the sphere on top and notice the sparks that discharge off. Sparks discharge because friction builds up a negative charge on the ball until the electric field becomes strong enough to carry the charge to the discharge wand.

Inside of the base is a motor that spins the belt on a felt covered cylinder. The friction causes electrons to leave the felt and travel on the belt to the sphere. The excess electrons give the sphere a negative charge. The discharge wand is connected to the ground port on the base. When the discharge wand is brought near the charged sphere, some negative electrons near the surface of the wand are repelled according to the **Basic Law of Electrostatics**:

Opposite charges attract and like charges repel.

An electric field exists between the sphere and the discharge wand. When the field becomes strong enough, ~~the~~ excess electrons will jump from the sphere to the wand. Making each momentarily neutral.

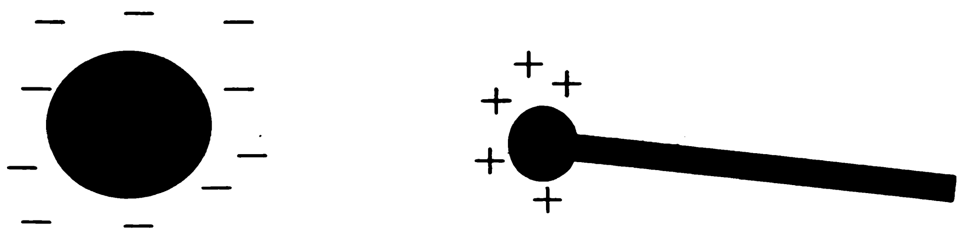


Figure 25: Induced Charge

Hint: To turn off the generator without being shocked, touch the discharge wand to the sphere while y

touch the controls.

Part 2: A <u>Hair Raising Experience</u>

For this next part, you will need a volunteer to help out. A good volunteer has fine, medium length hair without hair spray. Have the person stand on the milk crate and touch the generator. Turn it on and wait a minute. The person's hair stands on end.

When an object is charged, the charge spreads across its surface. For a person, each of the hairs gets the same charge and they repel each other.

When the person is done, use a meter stick to turn off the generator before the person lets go. **DO NOT DISCHARGE THE GENERATOR WHILE THE VOLUNTEER IS TOUCHING IT. THEY WILL GET A SHOCK!**

Part 3: <u>Flying Pans</u>

Set the tin can on the generator and place a metal plate on top of it. Stack up the five light aluminum pie pans on top of it. Turn on the Van deGraaff generator and wait a minute. As the charge builds up the pans will each have the same charge and will repel each other. They will fly off of the plate one at a time.

Part 4: <u>Franklin's Bell</u>

Mount two metal plates vertically on the foam board with a distance of 15-20 cm between them. Set the board on a stool or a milk crate. Connect the plates to the Van deGraaff generator. Use the insulated wires to connect one plate to the sphere and the other plate to the ground.

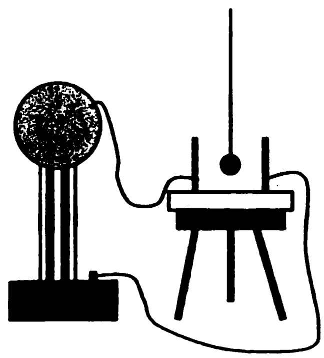
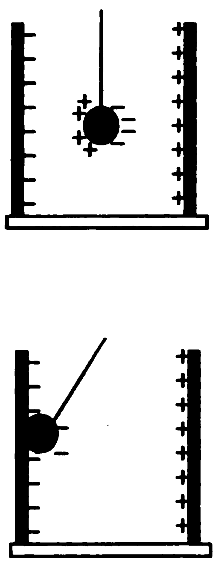


Figure 26: Franklin's Bell

Cover a small Styrofoam ball with aluminum foil and hang it from a string. Position the hanging ball so that it is between the plates. Turn on the generator and observe the motion of the ball between the plates.



When the generator is turned on, the plates get opposite charges. Furthermore, a charge is induced in the ball that is opposite the charge in the plates. The opposite charge on the ball is attracted to a plate and moves over until the ball hits the plate. When the ball hits a plate, it is charged by conduction and has the same charge as the plate that it hits.

Figure 27: Conduction and Induction in Franklin' Bell

Once the ball has the same charge, it is repelled by the first plate and swings to the second plate where it gets the opposite charge and is again repelled and the cycle continues.

Part 5: Spring Cymbals

Suspend a spring by a string from the ceiling. Attach a metal plate to the bottom of the spring so that the plate is parallel to the ground. Set another metal plate on the Styrofoam board resting on the milk crate. Align the two plates so that they are 10-15 cm apart.

Connect the Van deGraff generator to the spring and the bottom plate. When the generator is turned on, the upper plate accumulates a negative charge through conduction and the lower plate gets a positive charge through induction. The opposite charges attract and the plates are pulled together.

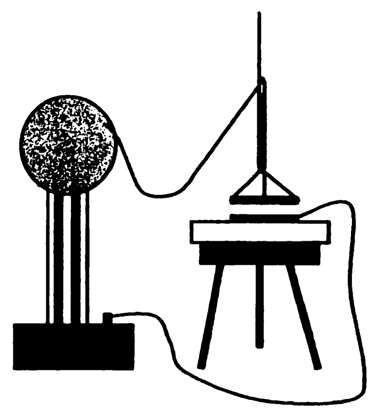


Figure 28: Spring Cymbals

Once the plates touch, the charges are neutralized and the spring pulls the plate back up.

Credits:

Parts 3 and 4 were adapted from descriptions and diagrams from the Physics Demonstration Lab at the University of Michigan. The information is available online at: http://www.physics.lsa.umich.edu/demolab/index.htm

Part 5 was adapted from diagrams from the Physics Department at the University of California at Bereley. It can be viewed at: http://www.mip.berkeley.edu/physics/D+0+0.html

Appendix B-VII: Be it Ever So Humble, There's Nothing Like Ohm

This demonstration will examine Ohm's Law and the distribution of voltage and current through a circuit.

Materials:

DC power source	Alligator clip wires
Voltmeter	Gooseneck camera and TV
Ammeter	Overhead Projector
Uninsulated copper wire	Nails
Play dough	

Part I: <u>Ohm's Law</u>

Ohm's Law describes the relationship between voltage, current and resistance. It is best described with the mathematical formula:

$$\underline{V=IR}$$

This first demonstration will show that at a constant voltage as the resistance of a material increases, the current decreases. Make a snake of play dough 2-3 cm in diameter and 10-15 cm long. Set it on the overhead projector. Position the gooseneck camera so that the meters can be seen on the television. Connect alligator clip wires to the elements as shown in the diagram below.

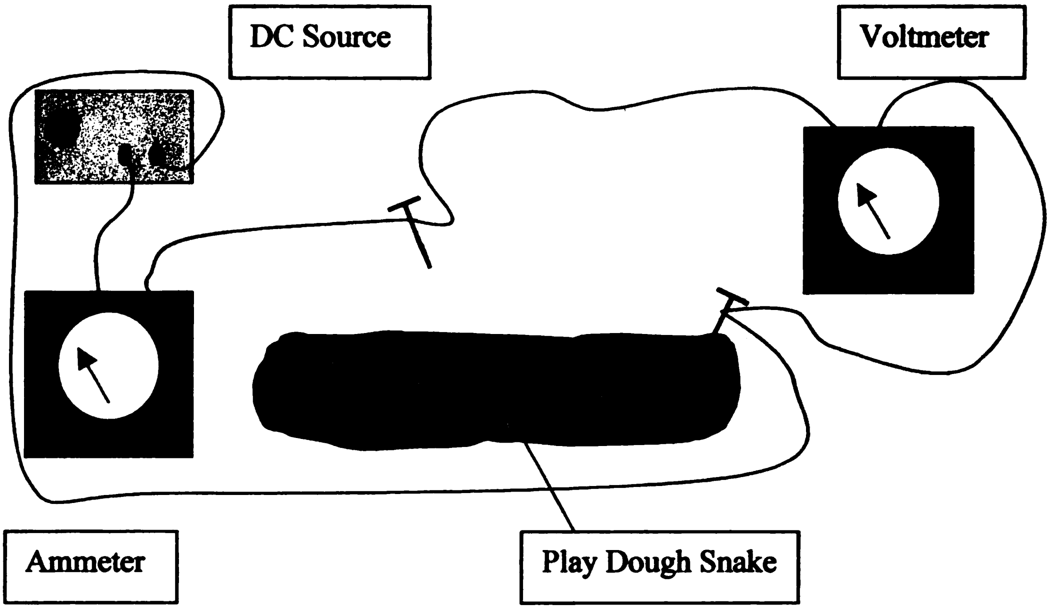


Figure 29: Ohm's Law Demonstration

Place the probe in the play dough. Adjust the voltage and show that increasing the voltage increases the current. Then leaving the voltage constant, move the probe along the play dough so that you are increasing the distance between the probes. This will increase the resistance in the circuit and decrease the current.

Part II: <u>Resistors in Series</u>

Make three play dough resistors, each tube should be 3-4 cm in diameter and 5-6 cm long. Also cut several lengths of bare copper wire each about 10 cm long. In this part of the demonstration we will be measuring current at a constant voltage. Remember that a decrease in current means an increase in resistance, for a constant voltage.

Set up one resistor and record the current flowing through it. Then use the copper wire to connect two together in series. You should notice that the current is approximately one-half of its original value. Now connect the third one in series and notice that the current is approximately a third of its original value.

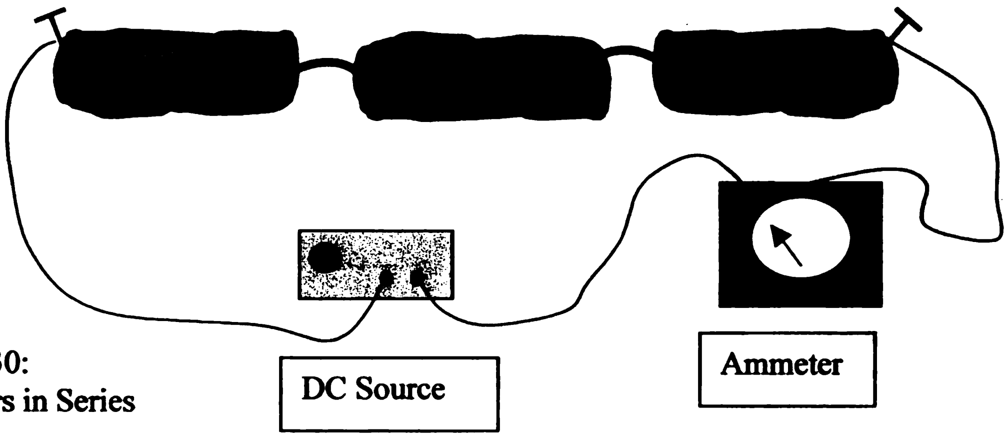


Figure 30:
Resistors in Series

Part III: Resistors in Parallel

Now connect two resistors in parallel. Notice that the total current is approximately twice that of a single resistor. This is because electricity has two paths to follow resulting in an overall circuit resistance that is less than that of a single resistor.

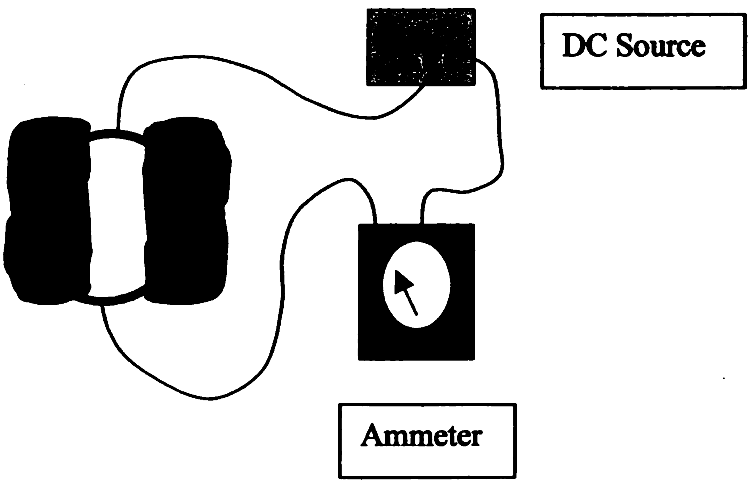


Figure 31:
Resistors in
Parallel

Part IV: Resistors in Series and Parallel

Finally, connect a circuit with two resistors in series connected to a single resistor in parallel. Use this setup to show the following.

1. The voltage is equal or each side of the parallel circuit.

2. The two resistors in series divide the voltage.

3. There is more current flowing through the lower resistance.

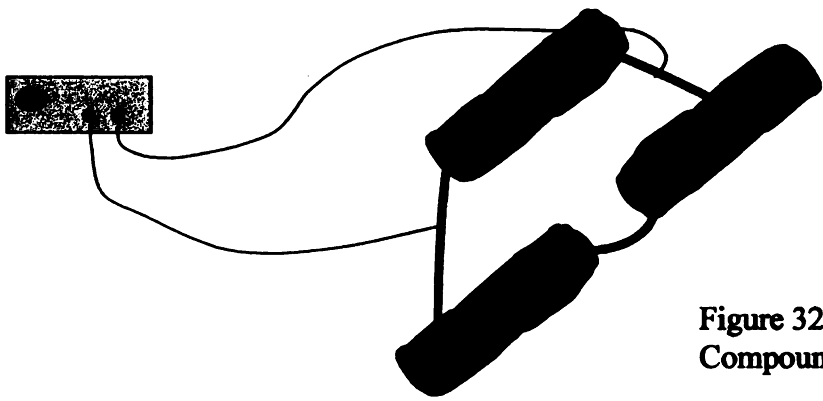


Figure 32: Compound Circuit

Credits: This lab was adapted from an experiment on resistivity produced by the Physics Department at Northern Kentucky University. Their experiment can be viewed at:

http://physics.nku.edu/GeneralLab/211%20Resistivity%20Resis-clay.html

Lab Observations: Be it Ever So Humble, There's Nothing Like Ohm

You will view a series of demonstrations presented by a group of students. In each case, you will be asked to make a prediction, record your observations and write a concluding statement to summarize the principle being shown.

Part 1

A. What will happen to the amount of current when the space between the probes is increased?

B. What happens to the current as the space between the probes is increased?

C. Write a statement that explains why the above observations occurred.

Part 2

A. What will happen to the amount of current in the circuit as resistors are connected in series?

B. What happens to the current as the resistors are connected in series?

C. Write a statement that explains why the above observations occurred.

Part 3

A. What will happen to the amount of current in the circuit as resistors are connected in parallel?

B. What happens to the current as the resistors are connected in parallel?

C. Write a statement that explains why the above observations occurred.

Part 4

A. Which branch of the circuit will have the greater amount of current flow through it?

B. Which branch of the circuit actually has the greater amount of current flowing through it?

C. Write a statement that explains why the above observations occurred.

Appendix B-VIII: Newton's Laws

Materials:

3- spring scale	Rubber bands
large book	100 g mass
string	500 g mas
Can	

Part 1: <u>The Inertia of a Book:</u>

Suspend a textbook from the ceiling by a thin string. Attach a second string to the bottom of the book. Tell the class that you are going to pull down quickly on the lower string. Ask them to predict if the upper or lower string will break first. Pull down sharply on the string, and the lower string will break. This is because the book's inertia resists the pull and breaks the string.

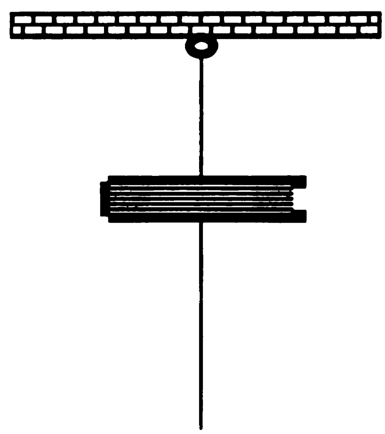


Figure 33: Inertia of a Book

Replace the lower string. Now tell the class that you are going to pull down on the lower string slowly. Again ask them to predict what will happen. Pull down slowly on the string and the upper string breaks. This is because with the slow force, inertia is not as much of a factor. The weight of the book puts more force on the upper string so it is the first to break.

Part 2: Hanging Spring Scale:

Hang a spring scale so that all can see. Place the 500 g mass on the scale and observe its mass. Remove the weight, hang a second spring scale from first. Calibrate the scales so that each reads zero. Ask the students to predict the reading on each scale when the weight is hung from the lower scale. Place the weight on the lower scale and observe that each scale shows the full weight.

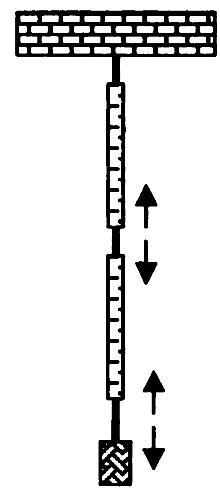


Figure 34: Hanging Spring Scales

At each point the weight being pulled down is equal to the force being pulled up. The weight pulls on the bottom scale and the spring pulls back on the weight. The lower scale pulls on the upper scale with its spring pulling back. The upper scale pulls on the support stand even though it isn't being measured.

Part 3: The Can Comes Back

Assemble a can as shown on the right. Roll it across the room and it will return. This is because of Newton's third law. As the can rolls, the weight winds on the rubber bands. As it unwinds the opposite force will push the can backwards.

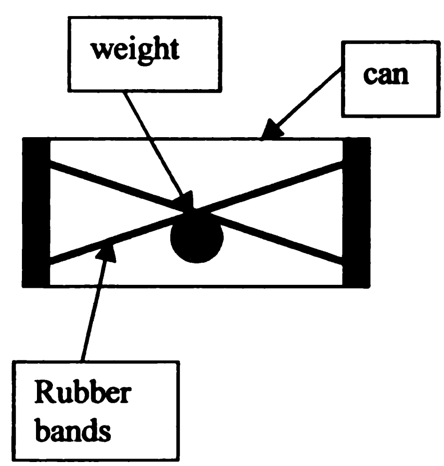


Figure 34: Returning Can

Lab Observations: Newton's Laws

You will see a demonstration presented by a group of students from your class. You will be asked to predict the outcome of the demonstration, record your observations and explain the results.

Part 1: The inertia of a book.

A. Predict which string will break when a sudden force is applied to the bottom string. Justify your prediction.

B. Which string actually breaks under a sudden force?

C. Explain the observation in part B.

D. Predict which string will break when a steady force is applied to the bottom string. Justify your prediction.

E. Which string actually breaks under a steady force?

F. Explain the observation in part E.

Part II: Hanging Spring Scales

A. Predict the reading on each spring scale when two are hung end to end and the weight is hung on it.

B. Observe what happens and record it below.

C. Explain why the scales read the weights that they did.

Part III: The Rolling Can

A. Predict what will happen to the can when it rolls across the floor.

B. Observe what happens. Record these observations below.

C. Explain the observations recorded in part B.

Appendix B-IX: Force Components

Materials

Small car	lead shot
PVC inclined plane rack	board for inclined plane
2 clamp pulleys	protractor
2 small weight buckets	spring scale

The inclined plane is set up in the rack. One pulley is mounted on the rack so that the string coming from the front of the cart can run parallel to the plane and over the pulley. The second pulley is positioned so that the string running from the center of the car can run perpendicular to the plane and pass over the pulley.

Find the weight of the cart using the spring scale. Measure the angle of incline of the plane. Calculate parallel force using the formula $f_p = f_w \sin\theta$. The parallel force is the component of the force of gravity that pushes the cart down the inclined plane. Place an amount of lead shot into one of the weight buckets so that the total weight of the bucket and the shot is equal to the parallel force. Now calculate normal force using the formula $f_N = f_w \cos\theta$. The normal force is the component of the force of gravity that pushes the cart into the inclined plane. Place an amount of shot into the other weight bucket so that the total weight of the bucket and shot is equal to the normal force. The two buckets are then placed on the appropriate strings. The board is removed but the cart does not move because the hanging weight is taking the place of the board.

When an object rests on an incline plane, its weight is divided into two forces. Part of the forces pushes the object into the plane. This force is called the normal force. The other part pushes the object down the plane. This force is called the parallel force. These two forces are perpendicular to each other and the weight of the object is equal to their vector sum.

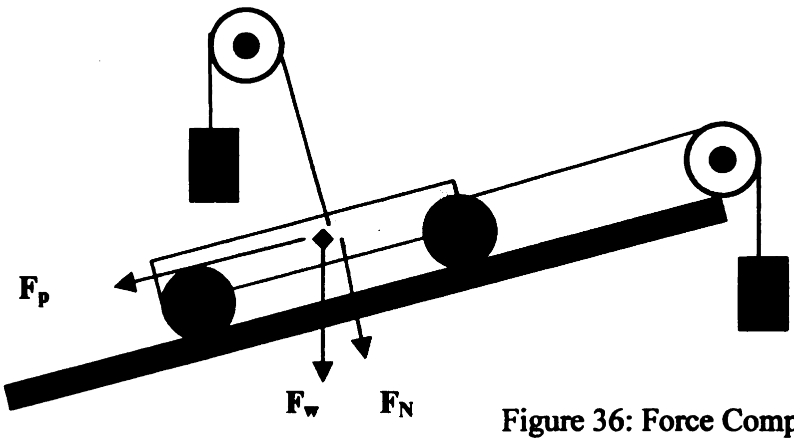


Figure 36: Force Components on an Inclined Plane

The angle between f_N and f_w is labeled θ and is equal to the incline of the inclined plane. The parallel force, as the side opposite of the angle, is equal to the product of the hypotenuse and the sine of the angle. ($f_p = f_w \sin\theta$) The normal force, as the side adjacent to the angle, is equal to the product of the hypotenuse and the cosine of the angle. ($f_N = f_w \cos\theta$)

When the object resting on the inclined plane is blocked, it will not move. The block pushes on the object with a force that is equal and opposite to the parallel force, and the plane pushes on the object with a force that is equal and opposite to the normal force. If these equal and opposite forces are replaced, the inclined plane is not necessary to keep the object in its inclined position.

Credit: Trinklein, Frederick E. 1990. Modern Physics Teachers Edition. Holt, Reinhart and Winston. T70F.

Lab Observations: Force Components

You will observe a classroom demonstration completed by a group of students from your class. Answer the following questions based on the demonstration.

1. Draw a free body diagram for the car sitting on the inclined plane.

2. Calculate the normal force and the parallel force for the car.

3. Record your observations of what takes place during the demonstration.

4. Explain the observations in #3.

Appendix B-X: Going into a Spin

This collection of demonstrations is designed to highlight various principles of circular motion.

Materials:

2 Tennis balls of different colors.	1 sturdy bucket with handle
String	nails or water for the bucket

Part 1: Rotational Speed Compared to Tangential Speed

Take two tennis balls. Make sure that they are different colors. Run a string through each and secure it with a knot. Make the length of one string 1 m long and the second string 1.5 m long. Go outside where there is a lot of room. Swing both over your head together. Point out to the class that both have the same rotational speed. This means that each will make the same number of rotations per minute. Now release the balls at the same time. Notice that the one with the longer string goes farther. This is because it has a larger tangential speed. Both balls are released from the same height and take the same amount of time to fall. Therefore the one that is traveling the fastest horizontally will go the furthest.

Part 2: Swing the Bucket

Get a sturdy bucket and fill it half way with either water or nails. Swing the bucket back and forth, slowly increasing the size of the arc. After the bucket is moving at the critical velocity, you will be able to swing it overhead without losing its contents.

As the contents are moving up, their inertia requires them to continue up or moving out away from the center of the circle. For an object on a circular path this effect of inertia is often called centrifugal force. The bucket (your arm) applies an unbalanced force on the contents of the bucket and causes it to move on a circular path.

A question to consider is what would happen to the water if, while the bucket was at the top of its arc, the bucket magically disappeared. Most students will predict that the water would fall. This is not true. The water would continue horizontally and drop, following the path of a projectile.

Credits:

Part1 is from the book: Serway, Raymond A. and Jerry S. Faughn.2002. Holt Physics Teachers Edition, Holt, Reinhart and Winston. 253.

Part 2: Department of Physics and Astronomy at the University of Minnesota. 2001. http://www.physics.umn.edu/groups/demo/demo_gifs/1D50_40.GIF

Lab Observations: Going into a Spin

You observe demonstrations on circular motion being presented by a group of students from your class. Please answer the following based on the observations.

Part 1

A. Predict which ball will go farther when they are released. Justify your prediction.

B. Observe what happens to the balls when they are released. Record you observations below.

C. Explain the observations in part B. Refer to the rotational speed and the tangential speed in your explanation.

Part II: The Swinging Bucket

A. Predict what will happen to the bucket as it is swung over the demonstrator head.

B. Observe what happens during the demonstration and record it below.

C. Explain the observations recorded in part B.

Appendix B-XI: Don't Rock the Boat

Materials:

1 large candle	1 hammer
2 large pins	string
1 12" ruler	

Part 1: Burning the Candle at Both End

Trim the candle so that each end has a burnable wick. Push the pins into the candle at the mid point so that it is balanced. Suspend the candle between two beakers and light both ends of the candle. The candle will rock back and forth on the beakers.

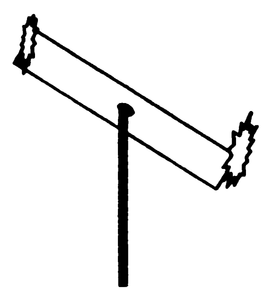


Figure 37: Rocking Candle

Torque is the product of force and length. As an end to the candle burns it reduces in both weight and length. The torque on that end reduces and that end of the candle rises. The lower end will burn faster because of its position. When the torque on the low end reduces enough, it will rise and the cycle continues.

Part 2: Defying Gravity

Set up the ruler and hammer on the edge of a table as shown in the diagram. Draw a diagram of it on the board or overhead and explain how all of the forces and torques are balanced.

On the ruler, the upward forces must equal the downward forces.

On the hammer, the upward forces must equal the downward forces.

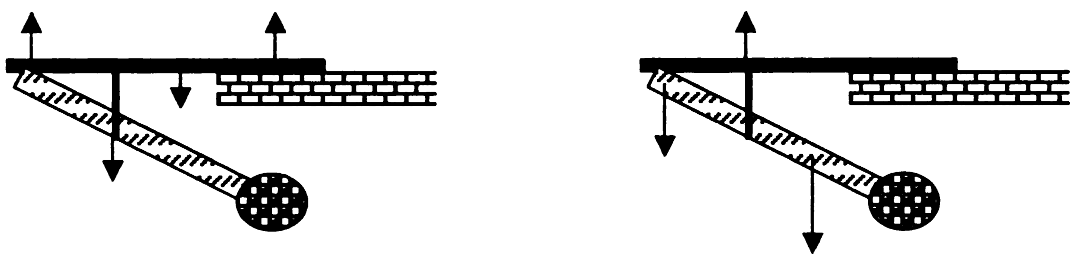


Figure 38: Forces on Ruler and Hammer

The torques around any fulcrum must also be equal. In this case we will consider the fulcrum to be the point where the ruler meets the table. Notice that there are no forces on the right of the fulcrum.

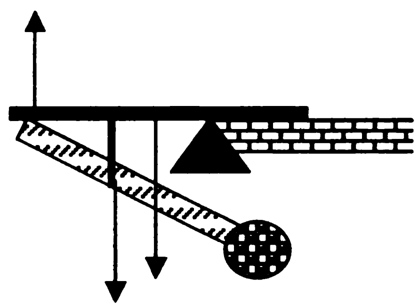


Figure 39: Torques on the Ruler

Credits:

Walpole, Brenda. 1988. 175 Science Experiments to Amuse and Amaze Your Friends. Randomhouse. 97.

Lab Observations: Don't Rock the Boat

You will observe a set of demonstrations being presented by a group of students from your class. Complete the following based on these demonstrations.

Part 1: Burning the Candle at Both Ends.

A. Predict what will happen to the motion of the candle when both ends are lit.

B. Observe what happens to the candle when it is lit and record your observations below.

C. Explain the observations recorded in B.

Part II: Defying Gravity

A. Predict what will happen to the hammer and the ruler when it is released.

B. Observe the motion of the hammer and ruler and record your observations below.

C. Explain the observations in B. Your explanation must include a free body diagram and a description of the forces and torques acting on the system.

APPENDIX C: DATA TABLES

Table 37: Comparison of Pretest and Posttest Data by Topic

Topic	Average Pretest Score	Average Posttest Score
Fluid Mechanics	26.7%	74.7%
Thermal Energy	23.5%	87.3%
Wave Properties	20%	88.3%
Sound	3.7%	68.5%
Reflection	18.4%	62.3%
Electrostatics	7.4%	88.0%
DC Circuits	9.8%	80.4%
Newton's Laws	10%	83.3%
Force Components	36.7%	75.8%
Circular Motion	8.8%	69.1%
Rotational Motion	14.7%	89.7%
Average	16.3%	78.9

Table 38: Semester End Comparison for Target Questions

Topic	Average Pretest Score	Average Posttest Score	Average Semester Exam Score
Archimedes' Principle	3.3%	63.3%	61.1%
Specific Heat	29.4%	94.1%	100%
Wavelength-Frequency Relationship	53.3%	86.7%	91.7%
Wave Properties	2.2%	82.2%	53.7%

Table 39: Comparison of Posttest Scores for Observers and Presenters

Topic	Average Presenter Posttest Score	Average Observer Posttest Score
Fluid Mechanics	75.0%	74.6%
Thermal Energy	88.9%	86.9%
Wave Properties	95.8%	86.5%
Sound	77.8%	66.7%
Reflection	72.2%	60.4%
Electrostatics	94.4%	86.7%
DC Circuits	83.3%	80.0%
Newton's Laws	87.5%	82.7%
Force Components	87.5%	72.9%
Circular Motion	75.0%	68.3%
Rotational Motion	87.5%	90.0%
Average	84.1%	77.8%

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