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Russell Lauren Billings

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ASSESSMENT OF THE LEARNING CYCLE AND INQUIRY BASED LEARNING IN HIGH SCHOOL PHYSICS EDUCATION

By

Russell Lauren Billings

A THESIS

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ABSTRACT

ASSESSMENT OF THE LEARNING CYCLE AND INQUIRY BASED LEARNING IN HIGH SCHOOL PHYSICS EDUCATION

By

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A 5-year research study was conducted on using the Learning Cycle and Inquiry Based Learning in the field of physics with 28 high school juniors. The objective of the research was to generally assess student success and response to the Learning Cycle and specifically assess students using one unit of instruction in that they enjoyed the instructional approach, learned the material as well if not better (than from traditional means), and demonstrated a proficiency of over 75% on tests and quizzes. The hypothesis was that the Learning Cycle would facilitate a greater learning and command of the concepts and make the subject matter more interesting, personal, and attainable to students. Qualitative data was analyzed, observed from the students' interest level of the subject matter, while quantitative data of student enrollment was collected, showing the increase at 56% over the course of the study. Additional quantitative data was collected from one group of 28 students in 2001 using test and quiz scores and a student survey that included a personal, written response. From the student written responses, 75% enjoyed using the Learning Cycle. 10% felt they adequately learned, while 32 % felt they learned *better* with the Learning Cycle. From the survey, 66 % had a favorable response to the Learning Cycle, while the rubric grading system that was used in the research measured the students' class average test scores at a competency level equivalent to 85%. This demonstrates that the Learning Cycle is an effective teaching tool, if not and does facilitate learning in an interesting way.

Dedicated to Mounir Awad,
a student and a friend,
for whom I have truly enjoyed
"sitting back and watching what the kid can do,"
for which there is no greater reward in teaching.

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Introduction

Science courses, especially those at the introductory level, have been characterized by some as boring and irrelevant to the world of the student. Several reports, including those from the National Research Council (1990) and Project 2061 (Rutherford and Ahlgren 1990), offer a grim view of the status of science education in the United States. Mix and coauthors (1992) conclude that science courses at all levels have fallen short in instilling an understanding of science, the processes of science and scientific thinking, and the relationships between society and science.

Most science courses are taught with the belief that students are empty vessels that need to be filled with large amounts of information. For the most part, this information is memorized for a test and then quickly forgotten. In addition, Mix et al. show that students who study more years of science dislike the subject even more than students with less science instruction. Educators have learned how to teach the traditional way by observing their best teachers, who in turn have learned by observing *their* best teachers. The traditional model of teaching exemplified is the "sage-on-the-stage" model.

It is a commonly held notion that teaching is the imparting of knowledge, i.e., that a concept can be transferred intact from teacher to student. In practice, what the student learns is a reconstruction of knowledge based upon the student's own memory bank of experiences and beliefs. This reconstruction is by no means an exact copy of what the teacher has presented. It may omit segments, alter some original components, contain information from the student's memory bank, and rearrange the sequence of components.

Augmenting this method of imparting knowledge, in many cases, is the heavy reliance on worksheets. Students are commonly supplied with ready-made data sheets for laboratory work on which they merely fill in the blanks. While convenient, the thinking required for the task often becomes rote, and the opportunity for creativity is minimized. Students would be better served by helping them organize their own investigations. The goal should be to allow students to think critically on how to organize and format their data in a clear and concise manner. For deeper understanding, students need to make inferences from their data while demonstrating the meaning of the independent and dependent variables.

Many of the activities carried out by science students merely confirm or illustrate what has been taught in class; or the activities involve a prescribed "cookbook" approach, in which students are instructed to follow the "scientific" recipe to obtain an expected result. While this approach may be useful in developing technique, it shouldn't be the mainstay of students' laboratory experiences. Students should do more of what scientists do: identify relationships to investigate, identify pertinent variables, devise a plan of investigation, control variables while conducting the investigation, record data, analyze data, formulate hypotheses, construct inferences, and make appropriate conclusions and predictions.

Science teaching needs, then, teachers who use instructional strategies that emulate the ways that scientists do science and who incorporate recent findings from the cognitive sciences. By actively participating in science students will gain and maintain their interest in the subject and learn the important lessons. If a "sage-on-the-stage" is the metaphor for the traditional passive learning environment, then "learner onstage, and support staff as stage hands, with the teacher directing it all" is the metaphor for student-centered learning.

Student-centered learning is not a new concept. Even in 1903, John Dewey complained that classrooms consisted too much of the "summaries and results of other people" wherein "the tendency is to reduce the activity of mind to a docile or passive taking in of the material presented." This statement made almost a hundred years ago is as relevant today as it was then. Thinking back upon my own learning experiences, it is true that much of what I encountered in the classroom was the summaries of what has been learned through the ages. Realistically, some of that cannot be avoided and is appropriate. But seeking instances where students can be put into student centered learning situations is a place to start making changes.

The premise of this thesis is that if I could articulate and achieve ideals of student-centered learning in well-chosen activities and labs, I would be serving my students well. This basic philosophy of student-centered learning guided my search for ways to improve my physics course, teaching style, and the learning environment of my students.

To begin to put students in the "driver seat" of their learning, I turned to the Learning Cycle Inquiry Strategy (SCIS, 1974) that supports student-centered learning. Using Learning Cycle Inquiry Strategy (LCIS), students are given a large number of activities--ranging from short "mini-labs" or activities, to more extensive and complex investigations. The overriding goal is to saturate students with a variety of experiences around the same concept or skill, in contrast to the traditional approach, which usually entails one isolated investigation of a theme or topic. It is through these multiple but

Learning cycle

varied experiences that students are able to effectively confront their preconceived notions with the reality of experiential evidence.

Constructing knowledge through the LCIS is an approach originating with the Science Curriculum Improvement Study (SCIS, 1974). This Learning Cycle is a teaching strategy that was first formally used in an elementary science program. Several studies have shown this technique has widespread applicability to a variety of grade levels, including college (Barman, 1992; Barmen, 1993; Purser and Renner, 1983; Saunders and Shepardson, 1987; Stephans, 1998). The Learning Cycle has been variously described, but in general consists of three phases: "Discovery & Exploration", "Structured Synthesis", and "Skill Development or Concept Application."

The first phase in the three-part cycle is an "Exploration Activity or Discovery Lab" devoted solely to cognition and comprehension, which may appear to the students as a collage of unrelated phenomena. During this exploration phase, students are engaged in solving a problem or a task. This challenge is open-ended enough to allow students to follow a variety of strategies, yet specific enough to provide some direction.

The purpose of this phase is to engage students in a motivating activity, requiring hands-on experiences and verbal interaction that provides a basis for the development of a specific concept or concepts and vocabulary pertinent to the concepts. This phase also provides an excellent opportunity for students to become aware of their personal ideas about natural phenomena and for instructors to assist students in questioning their understanding of the natural world and help them with misconceptions they may uncover. It is an activity to help motivate students through curiosity (right brain) and in which they record observations both qualitative and quantitative for later consideration (left brain).

While no explanation of the underlying principles is attempted in the exploratory phase, some aspects of the increasingly popular "problem-based learning" are incorporated here (Gordon 1998).

In the second phase, "Structured Synthesis," (which is the closest to a traditional lecture) the instructor gathers information from the students about their exploration and uses it to introduce the main concepts of the lesson and any related vocabulary. A structure of principles is integrated into a concept mapping of applications (right brain), which explains the previously observed phenomena. During this phase, the instructor uses textbooks, audiovisual aids, other written materials, or mini-lectures. The concepts are analyzed and proceduralized (left brain), in the familiar form of computational algorithms that apply the concepts. It is crucial to remind students during this phase that this lesson is the synthesis of hundreds of years of scientific development. To know science is to know these end results, but to think like a scientist, one should appreciate the history of science that brought us to our current understanding.

The third and final phase, "Skill Development or Concept Application" lets students study additional examples of the main concepts of the lesson or take on a new task that can be solved on the basis of the previous exploration activity and structured synthesis. Students either alone or in collaborating teams, use computer tools, network searches, and other related technologies to practice analytical procedures (left brain) and to characterize and synthesize new phenomena (right brain). This third phase is the "challenge project" in which students (or cooperative learning teams) evaluate the usefulness of the concepts when applied to an assigned project or task.

Unlike the three phase LCIS, the traditional lecture/laboratory course presents the topic of the day starting with a lecture that explains the fine points in detail. Then, an optional laboratory exercise follows to provide opportunities for students to observe different aspects of the topics discussed in the lecture. In most cases, the laboratory experience is considered a supplemental part of the lesson and is used primarily as a verification of the material presented in the lecture. In contrast, in the LCIS approach, laboratory experiences are viewed as an integral part of the lessons. These experiments are either used in the "Exploration Phase" as a vehicle to develop concepts and vocabulary, or in the "Skill-Building" phase as a means to enhance or expand concept development.

The emphasis on direct learning from activities and labs serves as a framework for students to construct concepts with guidance. Engaging in science facilitates the intuitive hypothesizing and inquiring that is latent in many young minds. This approach requires the teacher to be a kind of guide, a learning facilitator, rather than an imparter of knowledge. Instead of telling students concepts, the goal is to guide them toward constructing the concepts themselves. Students are far more likely to identify with, understand, and remember what they have figured out for themselves than what someone else has told them.

Current research supports the use of more concrete methods of teaching such as those incorporated into the Learning Cycle. Studies indicate that many students are less sophisticated in their thinking than sometimes assumed. These studies also indicate that many students would benefit from more concrete instructional methods, including hands-on activities and appropriate discussions related to these activities. For example, W.D.

Review of research

Popejoy and R. R. Schweers of Northern Colorado University (Bybee and Sund 1982) used the Burney test (Burney, 1974) to assess the scientific reasoning among 600 college students at a western university. Their findings indicate that 45% of these students required concrete instructional methods to understand most abstract concepts studied as part of their college curriculum.

During the 1992-93 academic year, the reasoning of introductory science students was assessed at a southwestern college and a mid-western university. Both institutions have a large population of nontraditional students; more than half of the students in these samples were 20 years of age or older. The Group Assessment of Logical Thinking test (GALT; Roadranka 1983) given to 48 introductory biology students indicated that 54% of these students would benefit from concrete instructional methods. The same test administered to 101 students enrolled in a basic college science course revealed that 72% of these students would benefit from concrete instructional methods.

In studies of the Learning Cycle implemented in college science classes, positive gains in student achievement were observed over the traditional lecture/laboratory format. For example, Wilke and Granger (1987) found that the Learning Cycle increased students' retention rate of biological concepts. Abraham (1989) reported that students exposed to the Learning Cycle in science instruction outperformed those taught with traditional methods and tests of the same concepts, and the groups performed equally well on tests of other concepts. In addition, Stephans and colleagues (1988) found that the Learning Cycle was more effective in bringing about conceptual change and understanding than a more traditional lecture approach.

When I first began teaching physics during the 1995-96 school year, I taught physics much the same way I had been taught, using the traditional approach. The physics I taught was a mathematical and lecture-based course, with an occasional demo or lab if time allowed. The mathematical based physics course was the only physics course offered in the curriculum at that time. After my first year of teaching at Kearsley High School, I began to infuse more and more activities into the classroom environment.

By the fall of 1999 a new physics course was added the curriculum, Paul Hewitt's Conceptual Physics Program for High Schools, 3rd edition (Hewitt 1999). The new text and supporting materials are based upon the LCIS and are designed to introduce new concepts through activities. Adding a conceptual based physics program allowed our school to meet the distinct needs of students, those needing the traditional mathematical physics (College Physics) and physics for students who are just trying it out to see if they have an interest in the subject matter.

With the new physics curriculum I began to do even more activities and labs within the newly created course. During this time I actively sought input regarding the learning experiences using the LCIS instructional format from my students both in classroom discussions and individually. Students, for the most part, looked forward to participating in activities that provided them some ownership for their experiences. The input that I received was very compelling, as was my observation of the number of students participating in learning. During lectures, one never really knows the true attentiveness of the students; during labs and activities I noticed that students who seldom seemed to be paying attention in lecture were some of the best lab learners.

In the second year of the study, I tried something new at the end of the school year: students participated in an interclass Physics Olympics competition. They were allowed to form their own groups and were given a daily challenge to meet within the allotted class time frame. The groups' overall grades were based in part on how they performed in relation to the other teams. The daily challenges were physics topics that we had covered throughout the school year.

Two things stand out from this experience: during the Physics Olympics I had 100% attendance for all 10 days (including senior skip day), and the students started the class without my prompting and in fact raced to get to my classroom! During lunch and after school students would come to see how their team was performing and to have some of their questions answered.

When this experience was completed, I surveyed the students about this experience in class using a discussion format. I was astounded at the interest level and the depth of the questions about their learning and ability to apply science concepts. The only complaint issued was that the grades were determined by how they performed against their peers. Here was a situation where I, as the instructor, took on the role of a facilitator, and had the pleasure of watching and helping my students succeed in a new and exciting way. As I continued to implement the Learning Cycle into more of the physics program, enrollment increased over the course of the study.

Observing the changes I had made in the curriculum and the success that followed, I have developed an increased interest in the success rate of Inquiry Based Learning and the Learning Cycle. To assess this, I examined the Learning Cycle in two parts: first, noting the increased student interest in active learning by charting the increase in enrollment over the course of the study, and secondly, formally evaluating the use of these methods in my classroom during the 2000-2001 school year at Kearsley High School in Flint, Michigan.

The goal of my research, then, was to modify the traditional science instruction format to incorporate the Learning Cycle, Inquiry Based Learning, and Constructivist Strategies to help make physics principles and processes "user friendly" to all students. The LCIS Inquiry Based Learning Methods require students to inquire and hypothesize about concepts individually and in groups to provide a common, personal experience with the concepts before, during, and after the teacher presents a lesson. This method should facilitate greater learning and command of the concepts while making the subject matter more interesting, personal, and attainable to students.

Twenty-eight students out of fifty-six students enrolled in two sections of Conceptual Physics at Kearsley High School in Flint, MI, elected to participate in the study. (The mathematical physics course was not offered during the 2000-01 school year due to a scheduling conflict and other curricular changes within the school district.) The students in this group were juniors (senior students would have been enrolled in the mathematical based physics course) who consented to being a part of this study. While the entire course was taught using the LCIS instructional technique, I chose to select one unit out of the course to focus the scope of my study and provide a "snapshot" of the LCIS strategy used throughout the school year. This "snapshot" of the study occurred over a period of five weeks beginning in the month of October 2000.

Students started each unit chapter with a set of activities. These activities were designed to foster interest in the subject area, while at the same time providing a consistent set of experiences for the class as a whole. After the students had some exposure to the concepts, they took part in a lecture/discussion to synthesize the concepts with the activities. Finally, they were assigned laboratory investigations to apply the concepts they had learned.

In order to assess the effectiveness of student learning in this part of the study, three areas were examined to measure the success of utilizing the LCIS instructional strategies: implementation of the Learning Cycle; rubric development and use in assessing student performance on activities and labs; and solicitation of student response to learning in a LCIS classroom using a survey which included an essay response.

Implementation

The Learning Cycle & Inquiry Based Learning

I began the school year (2000-2001) with an explanation of the Learning Cycle and an open disclosure to the students that this was somewhat of an innovative approach for me in my teaching as I intended to use these methods of teaching instead of the traditional lecture approach. When asked if they preferred to revert to the former approach, they declined and committed to the new one. This was consistent with the notion of shifting responsibilities for the learning process to active students, who become "partners in the process."

The unit I chose for part two of my research, States of Matter, was broken down into three chapters: Gases, Liquids, and Surface Tension. The activities used in this unit were designed to introduce and expand students' first experiences with basic physical phenomena about which they may or may not already have some prior knowledge. The emphasis during these activities, during the exploration and application phases, was on observing relationships, identifying variables, and developing tentative explanations of phenomena in a qualitative fashion. Some of the activities were more quantitative in nature and generally involved acquiring data in a prescribed manner. For quantitative activities, a greater emphasis was placed on learning how to use a particular piece of equipment, making measurements, identifying and estimating errors, and organizing and interpreting data.

Tables 1-4 outline these activities and demonstrate the three phases of the Learning Cycle: The Exploratory Phase activities (Appendix E) arranged from quick observations that took only a few minutes of class time for students to investigate to activities that needed one entire class period of 55 minutes; the Structured Synthesis Phase with a more traditional lecture; and an Application Phase where the students would do practice sets of the concepts first encountered in the Exploratory Phase.

Table 1: Study on Gases

Exploratory Phase	**Structured Synthesis**	**Application Phase**
Activity 1:The Magnitude of Pressure Shrink Wrapped Student Collapsing Can		
Activity 2: Pressure The Ratio per unit of Area		
Activity 3: Pressure Differentials: Fluid Flow		
Activity 4: Exertion of Pressure and Force: Levitation of a Student		
	Discussion on: Atmosphere Air Pressure	Exercise Set 1
Quiz 1		
Activity 5: **Bernoulli's Principle:** Air Stream between Objects Straw-Manometer Atomizer		
Activity 6: Fluids & Lift Airfoil Air stream Float Valve		
	Discussion on: Fast Moving Air	
Activity 7: **Streamlines & Drag:** Air Drag Balancing a ball in the Air		
	Discussion on: Streamlines	Exercise Set 2

Table 1 (cont'd)

Quiz 2		
		Lab 1: Levitation of Coins &"Wind Velocities"
Test 1		

Table 2: Study on Fluids

Exploratory Phase	**Structured Synthesis**	**Application Phase**
Activity 8 **Water Pressure:** Pressure as a function of depth, Transmission of Pressure within a fluid		
	Discussion on: Fluid Pressure	Exercise Set 3
Quiz 3		
Activity 9 **Archimedes' Principle** Displacement		
Activity 10 **Regulation of Buoyancy** Cartesian Diver		
Activity 11 **Buoyancy & Newton's Third Law**		
Activity 12 **Fluid Density & Buoyancy**		
	Discussion on: Buoyant Force	Exercise Set 4
		Lab 2: Calculating Buoyant Force
Quiz 4		
Test 2		

Table 3: Study on Surface Tension

Exploratory Phase	**Structured Synthesis**	**Application Phase**
Activity 13 **Shapes of Droplets:** Dripping Faucet, Liquids on various Surfaces, Drops of different substances		
Activity 14 **Cohesion & Adhesion:** Cork Flotation, Penny Displacement		
Activity 15 **Surface Tension:** Pepper float, Detergent propelled boat		Exercise Set 5
Activity 16 **Surface Tension** Water filled cups, Paper clip float, Liquid stream tension		
	Discussion on: Observations	
Quiz 5		
	Discussion on: Quiz results	
Test 3		

To assess student comprehension of the intended learning objectives, students were given two quizzes per chapter, generated from the test software from the Conceptual Physics Program. Each quiz was a multiple-choice assessment ranging from 10 to 20 questions. Students graded the their own quizzes during the same class period in which they had taken the quiz. To discourage cheating I had the students record their answers in a split sheet format. On the left half of the student answer sheet, students recorded the same responses on the right half of answer sheet. When finished, the right hand side of the student answer sheet was collected, and the remaining half of the answers were retained by the student for self-assessment. The answers were posted and students scored their quiz. I collected the scored quiz and compared it to the other half of the split answer sheet to keep the students accountable for their original responses by seeing that the answers matched accordingly.

Tests (generated from the Conceptual Physics Program software) were given at the end of each of the chapters that were in the unit. Whereas quizzes ranged from 10 to 20 points, tests ranged from 50 to 75 points. Tests were designed to measure student achievement and were placed in the curriculum at the end of each "chapter" where students had ample time and exposure to the objectives and concepts to be assessed.

Students spent five weeks working on this unit. The pace of the course was set in part by the success students were having with their work. With the emphasis placed on students learning directly from experiences, I found it necessary to "slow down" the rate at which I covered some of the course content. Students needed time to gather information as well as to derive meaning from this information.

The activities (A1 to A16 appendix D) served as the "Exploration or Discovery Phase" of the Learning Cycle. Typically students would start off the segment of the lesson with one or two of the activities listed. The activities themselves could either be very short "mini-labs" that required only a few minutes of class time to observe and collect data upon, or activities that required more class time. Students were required to record the date from the activities in their lab notebooks using a duplicate carbon copy method. After each activity, the class would engage in a discussion of their results.

The classroom discussions played a central role in allowing me to gauge the "success" of the students' experience as well as the experience itself. When engaging in these discussions, I would collect the students' carbon copy records of their results prior to the discussion. This allowed me to see firsthand how students were performing on the activity or lab. While I had their copies, they still had the originals, to which they could refer while participating in the discussion. During this discussion time ("Structured Synthesis", Phase 2 of the Learning Cycle) I encouraged students to make notations in the lab journals, which I would later collect, to look for evidence of students' active participation during these times.

I started the unit on Monday, October 2, 2000 with the chapter on gases with an Exploration Activity 1: the Magnitude of Air Pressure. During this first part of the Exploration Phase, students were asked to investigate the weight of air and the force it exerts. Students were given the handout for Activity 1 and a student volunteer was "shrink wrapped" to demonstrate the magnitude of air pressure. Students were instructed to record their observations into the lab notebooks.

After completing their observations of part 1, students went to their assigned lab stations to perform part 2 of Activity 1, in which they collapsed an empty pop can by creating a zone of low pressure inside of the can. Activity 1 took about half of the class period to perform and collect data.

Once every student had recorded their observations, I invited interested students to be "shrink wrapped." Students were amazed to experience what 14 lbs/in of pressure felt like. As homework students were assigned to complete the analysis questions and summary for Activity 1. Students were given handout for Activities 2 and 3 to organize in the lab books for the following day.

Tuesday, October 3, began with collecting the carbon copy of Activity 1 from students, and then individual students were called upon to share their answers to the analysis questions. After going over student answers, students began Activities 2 and 3. Activity 2 took all of five minutes for students to break a thin, wooden slat with a "newspaper." Students recorded their observations and immediately started working on Activity 3.

Activity 3 had the students investigating pressure differentials in another Exploration Phase. In part 1, students lit a candle and set its base in a pan half full of water and placed a jar over the burning candle and then recorded what happened to the water level inside of the jar as the candle burned out. In part 2, students burned a small piece of paper in a narrow mouthed jar. As soon as the paper stopped burning, students placed a peeled hardboiled egg on the lip of the jar and recorded what happened. With the remaining ten minutes of class, students were told that they must get the egg out of the jar intact (Skill Building) and were assigned to complete the analysis questions and summaries for Activities 2 and 3 for class on Wednesday.

Wednesday, October 4, started with the collection of the students' copies for Activities 2 and 3. Each analysis question was discussed in class and some students were called upon to read their written summaries of the activities. Once that was completed, a student volunteer was requested for another Exploration Phase to be levitated by straws in Activity 4.

This selected student sat on a 24 square inch board which was set on top of a heavy-duty plastic garbage bag. The edges of the garbage bag had been duct taped to a lab table, and ten more student volunteers were called upon to insert flexible straws along the sides of the garbage bag and, when ready, were asked to "blow." As soon as the student had been levitated, the students were asked to record the observations from Activity 4 and as a class we answered the analysis questions together.

Having completed four Exploration Activities dealing with air pressure the rest of the class period was devoted to "Structured Synthesis" in which a formal lesson was given about pressure, force and the atmosphere. Students were assigned an exercise set of questions from the textbook for the "Application Phase" of concepts learned.

The class resumed on Thursday, October 5, by collecting the carbon copy results from Activity 5 and students were given a homework check to make sure that they had completed the assigned exercise set. The next half of the class period was spent on discussing and going over the answers and student responses to the exercise set. After every student had the opportunity to have his or her question answered, the exercise set was collected, and students were given a short quiz over the pressure, force and atmosphere. Students corrected a copy of their quiz before they left class.

On Friday, October 6, the class was started by handing back the previous exercise set along with the next "Exploration Activity," Activity 5. In Activity 5, students observed the effects of fast moving air on various objects. They constructed a straw-manometer to measure pressure and created an atomizer. This activity took the entire class period as students had numerous tasks to complete and observations to record. The analysis questions and summary were assigned as homework.

On Monday, October 9, I collected the students' copies of the activity from their lab notebook. Each of the analysis questions was discussed in class and students were called upon to share their summaries. After a class discussion about Activity 5, students were ready to start Activity 6 in which students investigated lift, airfoils and flight. Activity 6 had the students construct a model airfoil with a sheet paper and a pencil; air streams were visited again as they used a small piece of paper and a spool to observe regions of high and low pressure; and lastly they constructed a simple float valve using a ping-pong ball, funnel and a straw.

The remaining class time was spent with the students recording their observations. Students were required to complete the analysis questions and summaries at home.

The following day, Tuesday, October 10, I collected a copy of Activity 6. A classroom discussion followed with going over the analysis questions to Activity 6. The discussion over Activity 6 set the foreground for the lecture (Structured Synthesis) on Lift and Bernoulli's principle. Students were assigned a set of questions from the text as part of the Application Phase of the Learning Cycle.

The lesson on Wednesday, October 11, began with going over the assigned exercise set from the previous day. Once student questions had been answered, the class began Activity 7. Activity 7 required students to investigate the concepts regarding air drag, streamlines and stability. Students worked the remaining class time on recording their observations. The analysis and summary were assigned as homework. which would be discussed in class the following day.

Thursday, October 12, students handed in their lab notebook copy of Activity 7. After the classroom discussion regarding Activity 7 was completed, a "Structured

Synthesis" lecture was given in which the concepts investigated by the students were presented formally to the students. Students were then assigned an exercise set as part of the "Application Phase" of the Learning Cycle.

Friday, October 13, student responses to the exercise set were gone over in class. The last half of the class period students took a short quiz over the concepts from Activities 5 through 7 and the two lectures. Students graded their own quizzes and began preparation for the lab on Levitation, Monday, October 16.

Monday started with a lab in which students determined the "wind" velocity needed, in miles per hour, to levitate a dime into a Styrofoam cup. With the remaining time left in class, students were given the opportunity to ask questions and clear up any misconceptions that may have existed regarding the concepts studied.

Tuesday, October 17, was test day and students took a 50-question test over all the concepts covered thus far in the unit. Wednesday, October 18,was spent going over the tests results and giving the students Activity 8 to prepare for on Thursday.

Table 2 (pages 22-23) shows the outline for the chapter on fluids as taught using the three phases of the Learning Cycle. On Thursday, October 19, students began the chapter on Fluids with Activity 8, Pressure as a Function of Depth. In part 1 of this activity students used a 2-L plastic pop bottle filled with water to measure the effects of depth on pressure by observing the stream ejection displacement from the bottle at different depths.

In part 2, a simple device was constructed which measured the transmission of pressure within a fluid. Students took the entire class period to finish this activity and the analysis questions and summary were assigned as homework. The following day, Friday, October 20, was spent going over student results from Activity 8, followed by a lecture (Structured Synthesis) on fluid pressure. At the end of the class period students were assigned an exercise set of questions from the text. The following day the beginning of class period was devoted to going over the students' responses to the exercise set and taking Quiz 3.

On Monday and Tuesday, October 23 and 24, students worked on Activities 9 through 12. Activity 9 started with having the students construct a simple boat, dealing with the concepts of Archimedes' principle and displacement. In Activity 10 the students constructed a Cartesian diver to investigate the concepts of buoyancy. Activities 11 and 12 investigated the relationship between fluid density and Newton's Third Law of Interaction. Students were required to submit their results on Wednesday, 25 October. After a classroom discussion over the activities, a lecture (Structured Synthesis) on the concepts from the activities followed. Students were given an exercise set from the text to answer.

Thursday, October 26, the exercise set was discussed in class and students performed lab 2 in which they calculated the buoyant force acting upon an object. Friday, October 27, followed with a discussion of the lab results and Quiz 4. Students received feedback from the quiz and were asked to prepare for Test 2 on Monday, 30 October.

The chapter on Surface Tension was started Tuesday, October 31, with Activities 13 to 16. In Activity 13, students looked at how surface tension of different substances affects the shapes of droplets. Activities 14, 15, and 16 had students experimenting with surface tension, cohesive and adhesion forces. The activities lasted through Wednesday, November 1. A lecture was given the last half of the class period on Wednesday (Structured Synthesis). On Thursday, November 2, Quiz 5 was given with student self assessment and a brief discussion time that followed. On Friday, November 3, students took Test 3.

Development of a Rubric

The challenge in this study was to measure accurately student competency or success in the "Exploration/Discovery Phase" or the "Skill Development/Application Phase" during laboratory settings. To this end I developed a rubric (Appendix A) that served as a scoring guide that was given to students at the start of the school year. A rubric is a scoring guide that is given to students in advance, that demonstrates what each of the scored items means. I chose to use a 4-point rubric, where a "4" was considered "experienced" and a score of "1" indicated "lack of competency." Each of these rankings was well defined to students and examples of lab reports were made available for students to see what a ranking of 4 required.

While I referred to my scoring as "holistic," many of my students began to refer to the scoring as "holocaustic"! Some of them held the notion that just by doing the activity and making an attempt they should receive a "decent" grade. But using the rubric, if a student handed in a partially completed lab, it would receive a rubric score of only 1 or 2 (Appendix A). In past experiences, students could receive a passing grade without having completed an assignment.

Student Grades

For this course, a student's overall grade was determined by weighted categories: Tests & Quizzes (50%), Labs & Activities (30%), and Exercises & Coursework (20%).

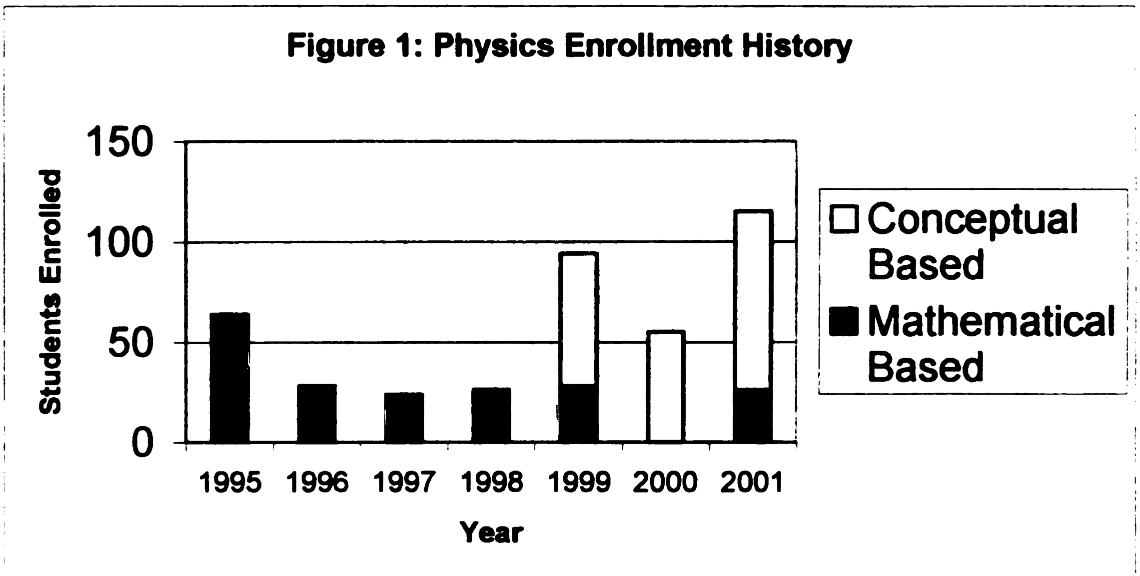
The rationale for allotting 30% of the overall grade to be determined from the labs and activities was to ensure grade equity. The labs and activities were designed and selected to help students master the learning objectives that were set fourth at the beginning of every chapter or unit. Since students were required to work in a group format it became difficult to determine if every student in that group was actually a contributing member or not. Quizzes and Tests assessed the individual student's mastery level of the aforementioned objectives. As such, having at least a 50% grade determination from quizzes and tests helped assure individual accountability in each student's overall grade.

Student Survey and Comments

Students were given a fifteen-question survey at the end of the 2000-2001 school year, which included a personal, written response. This survey was given to assess the students' perceptions of having been taught using the LCIS method for the entire school year. The survey was given to the 28 students who agreed to participate in the study on the last day of class with the entire group responding to the 15 questions. These same students were also given the opportunity to express comments about their thoughts and feeling after having been a student in LCIS based classroom. Out of the twenty-eight students in the study, 24 submitted a comment.

Evaluation

This research study was twofold and assessed as such. In Part 1, individual and group responses were solicited over the course of the study regarding student interest in the Learning Cycle and were assessed by the increased enrollment in physics over the course of the study.

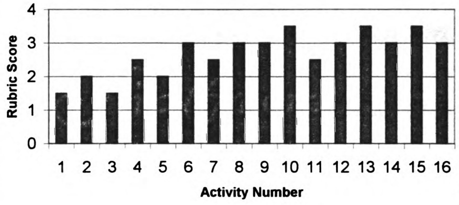


As Figure 1 shows, in the fall of 1995, the number of students enrolled in physics numbered 64. This number has gradually increased to where the enrollment for the fall of 2001 stands at 115 students. Enrollment has almost doubled, and I attribute much of this increase to the gradual shift to student centered learning.

Part 2 of the study, the evaluation of the 28 students in 2000-2001, was assessed using rubric scores on lab and activities, tests & quiz results, student statements and lastly, a student survey given at the end of the school year. These evaluation methods, along with my general observations over time, have afforded insight into the results of teaching based on the Learning Cycle.

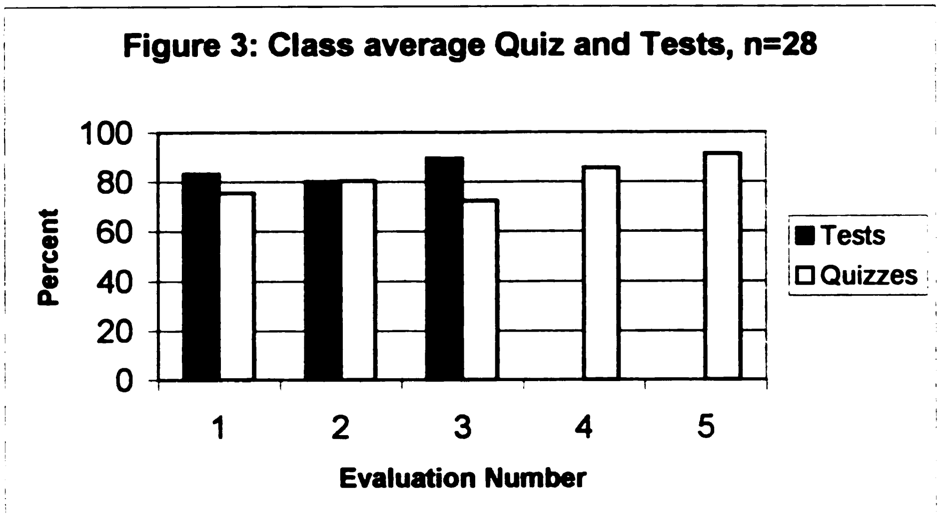
Figure 2 shows the average student score results based on the holistic rubric-grading guide of the sixteen activities. One can see that at the beginning of the unit (Activities A1 to A5, Appendix D), students were still in the transition stage, as defined in the rubric guide, of reporting their results. Over time, one can see a gradual improvement in students' scores using the same scoring guide as they gain more practice. Regardless of the length or difficulty of the assigned task, students' results were assessed using the same rubric.

Figure 2: Class Average Rubric Results for Exploration Activities, n=28



The unit studied contained in-depth quantitative lab experiences (Appendix E). Class averaged rubric scores on these labs averaged 2 and 2.5 respectively. These results along with the exploratory scores put students in the transitional category on the rubric scale.

Using the test & quiz questions generated by the software provided with the physics program, I compiled the class average results as shown in Figure 3. For tests and quizzes, the class average results were above a grading score of 75% in all circumstances, which would be considered a high score on an absolute grading scale.



Statements collected from students during the 2000-2001 school year (Appendix C) were positive overall to the LCIS. Students participating in this study were asked to respond in writing the thoughts about the experiences they had throughout the course of the year. One student responded with the following statement,

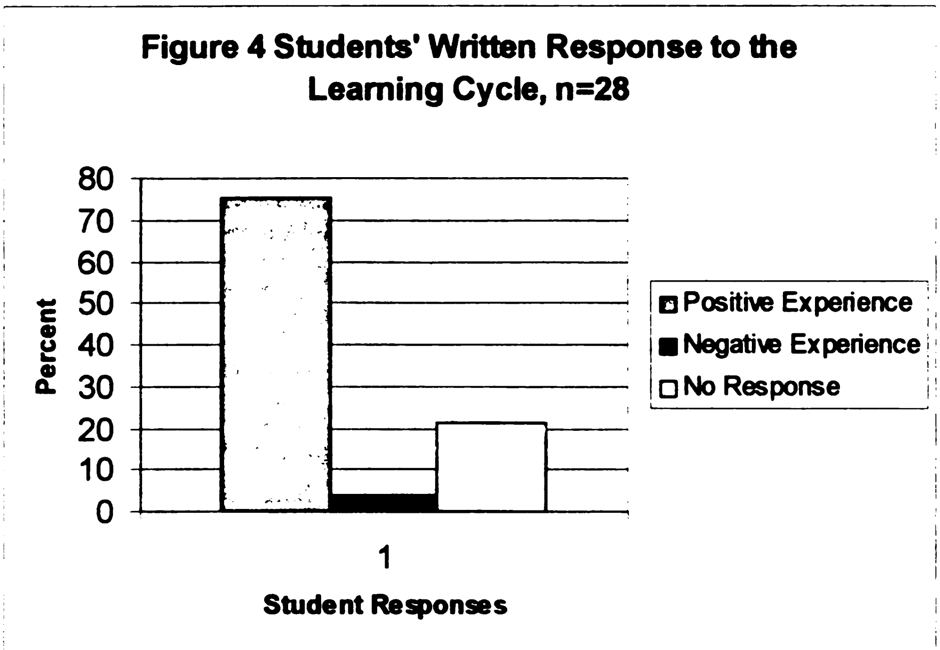
"I would have to say that there is nothing worse than [sic] sitting in a class and listening to a boring teacher talk your ears off for an hour. I like the hand [sic] on classes and I feel that you can learn a lot more when you have something to work with in front of you. Letting the student learn his own way, whether by trial & error or by introducing a new concept to him and than [sic] sitting back and seeing what the kid can do with it, is a good thing."

Another student responded that,

"I would rather have been introduced to new concepts <u>before</u> starting labs. My reason is that when we did a lab with no background we had no way to tell whether we

had done it correctly. On the other hand, when we started with a lab, I was able to derive meaning behind some of the concepts, although this was sometimes incorrect. I did enjoy the class, mostly because I like to learn hands-on rather than from the book."

The following graph shows the results of the students' experiences with the Learning Cycle from all of the written responses:

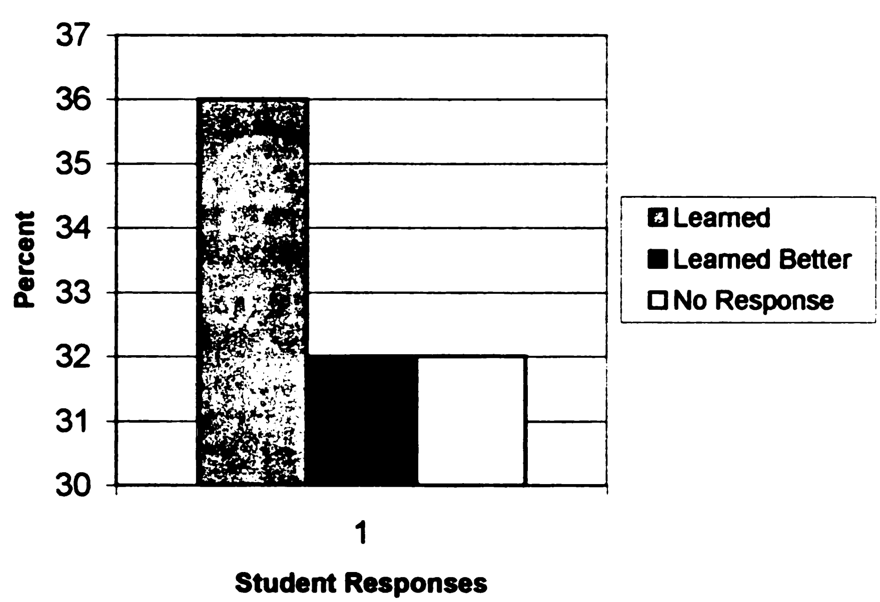


Students overwhelmingly agreed that the use of the Learning Cycle was enjoyable and "user friendly." As shown In Figure 4, 75% of the students enjoyed using this method of learning. Results for these findings were derived from the direct statements taken from the written responses, such as *"I enjoyed your class,"* or *"This class was fun."* Indirect statements such as *"This was a great class,"* or *"I give this class an 'A',"* were inferred as positive responses as well. (Appendix C)

The sole negative response, representing 4% of the class, was inferred from the statement, *"I would give this class a 'D."* 21% of the students made no reference to their personal feelings or experience regarding their interaction with the Learning Cycle.

The enthusiasm reflected in the responses (Appendix C) and the tabulation of these responses as 75% favorable to the Learning Cycle provide that there was great student interest and support for the use of the Learning Cycle in the high school physics classroom.

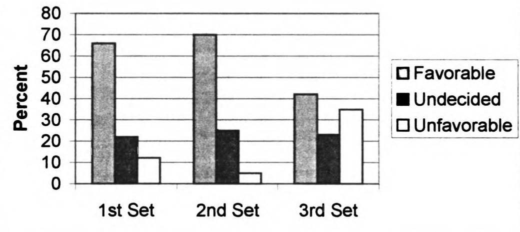
Figure 5: Students' Perception of Learning with the LearningCycle, n=28



While Figure 4 shows that 75% of the students enjoyed using the Learning Cycle, Figure 5 shows that only 32% felt that they learned *better* using its approach. However, 36% stated that they *did learn* the material and, as reflected by the Figure 4, enjoyed doing it. Thirty-two (32%) of the students made no reference to their personal learning or did not respond at all. Results were derived from direct statements or indirect references taken from the responses such as, *"I learned much better...,"* or *"I can better understand how things are,"* or *"I found this new way of teaching easier to use."* (Appendix C)

Student survey questions (Appendix B) were broken down into three categories and were answered in response to completing the unit on states of matter. The first category (questions 1-5) was constructed to determine the success of using activities before formal instruction in terms of concept comprehension and student interest. The second category (questions 6-7) was designed to ascertain the effectiveness of having students working in small groups. The third set of categories (questions 8–15) focused on student response to the analysis Skill Building phase of the Learning Cycle. When examined by sets, as in Figure 6, the result s show support from students.

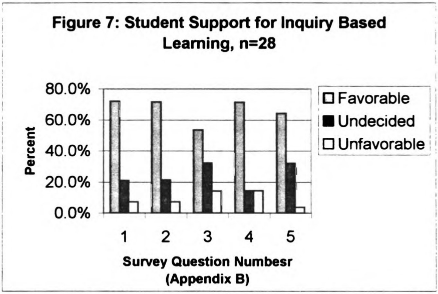
Figure 6: Summary Results of Student Survey, n=28



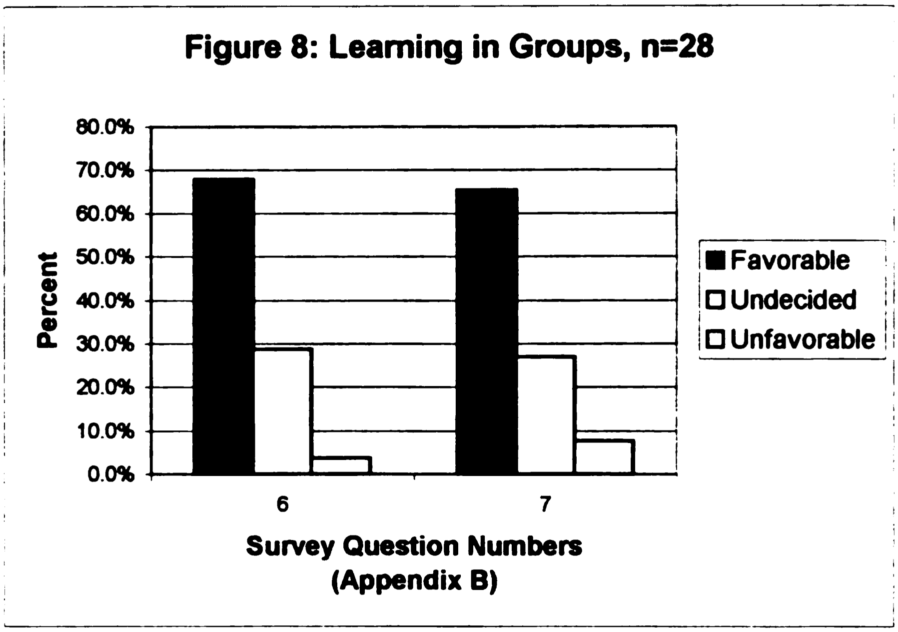
For simplicity, I chose to combine responses that were either above the mean choice or below the mean choice. As such I combined the "Frequently" and "Always" responses into a "Favorable"; "Sometimes" as "Undecided"; and "Never" and "Not

Very" as "Unfavorable" responses. Combining results in this way allowed trends in the data to be better highlighted.

The results from the first set (questions 1-5), Figure 7, indicate a favorable response to this method of learning. However, the average of 67% favorable responses is not a strong support of Inquiry-Based introductions. The responses in the "Unfavorable/Undecided" categories, taken together, were 34% of the total responses. The highest number of "Unfavorable" responses came from questions 3, 4 & 5, which indicates that students have reservations regarding the effectiveness of conducting an activity with little or no teacher instruction prior to that activity.

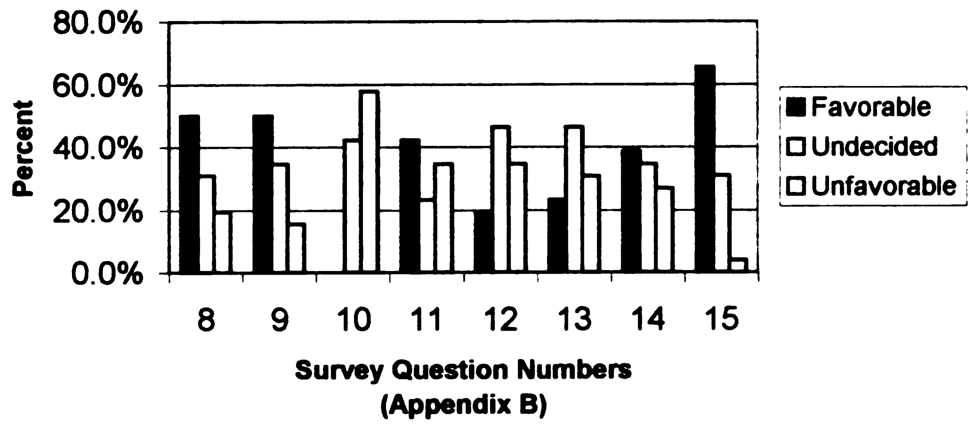


The second-set of questions (6 & 7) assessed students' perception of working in a group-learning environment. Figure 8 shows that the 68% of students felt that they benefited from working in a group setting when performing labs and investigations. The "Undecided" category may reflect the variability of students being paired with different students on a regular basis. Most students have a strong preference as to partners for group work.



The third set of questions on the survey (questions 8-15), Figure 9, evaluate whether students understood the analysis component (part three of the Learning Cycle) of their investigation. The first two questions of this set address students' perception of their questions being answered by either the activity or the teacher. For both of these questions cases only 50% of the students responded that their questions were answered adequately.

Figure 9: Investigation Analysis, n=28



One of the key components of Inquiry Based Learning is the need for multiple exposures to the phenomena that students are expected to learn. Rather than validating some scientific law or physical property, students are expected to perform a series of small investigations along with some in-depth lab work (Appendix E). The risk in this form of instruction is that students will be bored with numerous investigations. Students were surveyed in question #11 to assess their perception of these activities as being either redundant or unnecessary.

From the survey, 42% responded with satisfaction regarding the numerous experiences doing investigations and labs. Twenty-three percent (23%) found that sometimes the activities were redundant, while approximately 35% found the multi-exposure to various experiences unnecessary. If both the "Unfavorable" responses and the "Undecided" responses were collectively added together, the percentage of students feeling unsatisfied with the multi-experience learning method approaches was almost 58%. Evidently, many students find the multiple exposures with the same simple phenomena to be too repetitive.

The 58% unfavorable spike in Figure 8 shows that students responded unfavorably to question 10, which corresponded to students finding the post-students labs redundant after the exploration activities. In other words, students were reluctant to go into the lab setting after having been exposed to the concepts in the Exploration Phase. The post student labs come after the activities and are designed to have the students *apply* what they have learned from Phase 1 and 2 of the Learning Cycle, yet many of the students found this application phase cumbersome and unnecessary as it seemed repetitive. In actuality, this phase, if approached properly, allows for the greatest critical thinking. Finally, the spike over 65% favorable response in Question 15 was positive for the students, indicating that students enjoyed their overall Learning Cycle experience.

Discussion

Using the Learning Cycle and Inquiry Based Learning techniques provides some potential benefits as well as some unique challenges. Like most choices, there is always a trade-off of one thing for another. In Inquiry Based Learning, the trade-off is loss of traditional structure for the student for the expectation of true educational insight. The challenge in the classroom is to carefully nurture and develop curiosity through a facilitating learning environment.

Ideally, scientific research depends upon a control used throughout the experiment. One of the greatest limitations in this study, which is a problem in educational studies, was the lack of a control group. In a more complete study, one class of students would be given instruction in the traditional lecture, exercise and lab/activity, while a different period of the same course would receive the Inquiry Based Learning method. While this approach would offer more quantifiable results, it does not merit the support of either the administration or parents. Complaints could have been voiced, as the study could be viewed as an inequity of instruction between two different class periods for the same course, by the same instructor.

While it may initially appear that the instructor can take a less active role in this model than the teacher-led model, the truth is that it takes a great deal of attentiveness and patience to guide students in their pursuit of the intended learning goals. Just as students need to make careful observations during their investigations, so does the instructor need to monitor the progress of his/her students. If students are becoming too frustrated, the instructor needs to step in and offer encouragement and guidance. Likewise a "comfortable" pace needs to be set in which the instructor guides students in this type of learning. "Too fast" and students will become discouraged, "too slow" and students lose interest. Survey data, along with increasing enrollment histories for this class, demonstrate some success in utilizing the LCIS instructional methods.

Since students predominantly have learned thus far from traditional methods, they need to be guided gradually into working into the LCIS format. In the case of this study one five-week unit was taught solely using the Inquiry-Based Method, and this clearly was effective for many, yet not all students. Of the student responses collected, few were negative (Appendix C), but some students felt uncomfortable with the format while others felt that some explanation was needed prior to the experiences. Nevertheless, some showed interest in their own learning and encountered a positive experience in science. It is hard to expect students to want to consider pursuing science unless they have a good experience with it. At the onset, Inquiry Based Techniques need to be coupled with some traditional methods to facilitate critical thinking, yet provide a familiar structure through which to nurture this essential skill.

Critical to the success of this or any other instructional tool is the way that it is used and how students are measured with it. To this end, having a well-defined rubric to grade laboratory exercises was key to guiding students into a successful experience. I don't think that students would have fared as well using some generic point scale to determine their grade. Using a rubric effectively communicated the expectation level to the student.

One benefit of using a rubric is that it models what is expected of the student. This alone has affected the number of incomplete labs and investigations handed in, where students failed to answer <u>all</u> of the assigned questions or tasks they would receive a failing score from the rubric. For some students this is frustrating, as in the past if they answered eight out of ten questions they would at least get a score of 80%, which is above average on a total point grading scale. But from my experience, the questions that they most often chose not to answer are the very questions that lead to depth of understanding. In this regard, using rubrics has been helpful in increasing the frequency of fully completed work handed in by students. The 1995-96 through 1999-2000 school years, 80% of the students were handing in their labs incomplete; with the implementation of the rubric grading system the percentage of completed labs turned in at the due date averaged 92%.

The results of the written student responses showed that 75% of the students responded favorably to the Learning Cycle and 68% felt they learned the material. Given the stated results, however, an analysis of the survey determined that while many students may have enjoyed the freedom of self-discovery they did not fully master the concepts and thus total learning was compromised. The survey questions designed to assess the success students had formulating questions and hypotheses in terms of both pre and post activity learning settings received the lowest marks, while the questions addressing the effective answering of conceptual questions came in lowest. This suggests that students lack a sufficient knowledge base of the subject matter to be studied to formulate their own questions and answers based upon their own observations.

As stated, the survey indicated that students were most uncomfortable with the pre-lesson task of formulating questions and hypotheses. While this is an important skill to develop, it must be carefully done under the umbrella of a common goal. In our task-oriented, goal-driven age, students are programmed to find the end result and thus lack direction when an intended goal is not explicit. Providing a goal, but without predicting a result, at least may require students to think at a deeper level for some applications.

Students commonly believe that they have sufficient knowledge about what they are going to study. However, the fact that an average of 70% of the students gave unfavorable responses to the Exploration Phase of the LCIS shows either one of two things: that either the students believe that they have a strong knowledge base, or that they really lack a clear and basic level of understanding about the investigations in which they have participated. In their ignorance, quite often students believe that they already have a sufficient knowledge base and therefore should not be "forced" into conducting basic experiments and activities in which they already have a knowledge base. This indicates a clear need to have students share a common experience through a controlled lab setting. It is from this experience that the class as whole can move forward as it ensures that everyone has experienced the same phenomena.

One of the challenges in teaching is making the choice between topic coverage and content. Some courses are taught as an overview with the goal of exposing students to a wide range of topics within the subject area. The other choice is to teach not so much for coverage but for either depth of understanding or experiences. Using the LCIS approach does take more time (5 weeks to cover 3 chapters, instead of the 3 weeks as suggested by the text for a course overview).

Continuing to teach using the LCIS methods will result in less material being covered but with more student experience in the lab setting. However, I attribute the 56% increase in student enrollment in both the mathematical and conceptual physics over the course of the study to the primary use of LCIS as many hands-on learners master the concepts in the conceptual course and are inspired to tackle the more mathematical based program the following year (Appendix C).

While students seem to enjoy hands-on learning experiences, they are reluctant to quantify their results. Extrapolating meaning from experience is a far cry from having an instructor hand the understanding to the student on a silver platter. Students want to have it both ways. They seem to want the independence to "explore", yet they also want to be told what to expect and the answers to the questions presented. I find that students rely heavily upon each other in a group-learning format. Due to a number of limitations of both equipment and space, students are required to work in lab group sizes ranging from three to five students. This creates an opportunity for one or two people to "dominate" the group and the results.

Questions 8-15 in the student survey highlighted one potential weakness of the Learning Cycle Inquiry Strategy instruction technique. Students are used to having a "cookbook" approach in lab settings and have not developed the skills to answer questions using critical thinking. Without the answer being "spelled out" by the instructor in a "fill in the blank" format, many students struggle to synthesize their lab results. This conclusion is based on my observations and having students repeatedly ask me to tell them the correct way or even answers to the problem they have been assigned to investigate. Many students get frustrated when I remind them that there is often more than one possible solution to the problem(s) at hand.

Critical to the exploration phase of the Learning Cycle are two key components: first and foremost, the data gathered by the students must be accurate and secondly, it must be analyzed in post lab discussions. In retrospect, a carefully focused post-lab discussion did not always occur and that is accurately reflected in responses in the survey.

To address this problem, I intend to have a structured format for guided group discussion after each pre, mid, and post Inquiry Based activity in the future. Intermingled with these activities should be instructor led "informatives" where the basic elements of the concepts are outlined, thus laying the foundation for the teacher-student concept discovery Inquiry Based activities. The combination of these activities and the skeletal structure of traditional teaching methods will better create an atmosphere where critical thinking can take place.

Providing students with a common set of experiences is key in gaining basic understanding for the classroom. Therefore, Inquiry Based Learning can still be regarded as an effective tool, yet not a comprehensive method for teaching students. Used in the proper context, the tools and techniques of Inquiry Based Learning can facilitate a greater learning and command of the concepts while making the subject matter more palatable, personal, and attainable to students.

Overall, I am pleased with the results that I have seen from students utilizing the LCIS approach. While not all students learn in the same manner, I am finding with experience that some material is best presented in the LCIS format, while other material is best presented in the more traditional format. What is essential is using a variety of teaching techniques with the hope of reaching a broader spectrum of learners. Based upon the increased interest that I see in the classroom on a daily basis, the increasing enrollment, and positive comments from students of utilizing the LCIS approach, I can see students taking interest in science and I have enjoyed helping them gain greater understanding of the world around them.

APPENDICES

Appendix A:

Rubric Grade Determination for Laboratory Investigations

5 100% Superior.

4 95% Experienced.

- Excellent technique was used throughout the lab procedure. Procedures were well - planned and well -executed.
- Data and observations were recorded correctly, descriptively, and completely, without serious errors.
- Calculations and data analysis were performed clearly, concisely, and correctly, with correct units and properly performed calculations.
- Graphs, if necessary, were drawn accurately and neatly and were clearly labeled.
- Demonstration of the connections between their observations and the related physics concepts; this understanding was expressed clearly and completely.
- Good reasoning and logic are evident throughout the report.
- Answers to analysis questions were complete and accurate.
- Summary include what was done, without restating the experiment or data, the significance of the results and the relationship, if any, between the variables observed.

3 85% Competent. This is the STANDARD

- This is the standard. No errors in technique were observed during the lab.
- Data and observations were recorded correctly, descriptively, and completely, with only minor errors.
- Calculations and data analysis were performed correctly, with correct units and properly performed calculations, but the work may have been slightly unclear or disorganized.
- Graphs, if necessary, were drawn accurately and neatly. Most of the major components needed for the graph were included. (Descriptive title, labels and units)
- Effective expression recognizing the connections between your observations and the related physics concepts.
- Good reasoning and logic were evident throughout the report.
- Answer to analysis questions are correct, but may reveal minor misunderstandings.
- Summary statement includes key concepts and relationships in terms of what the outcome and the significance of the results.

2 65% Transitional

- Only a few errors in technique were observed during the lab procedure, but they were significant. Procedures were not well planned or they were carried out in a disorganized fashion.
- Data and observations were recorded adequately, with only minor errors or omissions.
- Calculations and data analysis were performed correctly, but minor errors were made both in calculations and in applying correct units.
- Graphs, if necessary, were drawn adequately, but labels or title or units are missing.
- Reasoning was weak throughout much of the report.
- Some answers to questions were incorrect because of misunderstandings, minor errors, or poor data.
- Summary was included, but it merely restated the procedures, questions and/or data missing key connections.

1 50% Inexperienced

- Many serious errors in technique were observed during the lab procedure. Procedures were very poorly planned and disorganized, and they show a lack of understanding of the lab.
- Data and observations were incorrect or incomplete.
- Calculations and data analysis were performed incorrectly, with no units or with incorrect units.
- Graphs, if necessary, were drawn incorrectly.
- It was obvious you did not recognize connections between your observations and the related physics concepts.
- Errors in logic are made throughout the report.
- Some answers to questions are so incorrect that it is obvious that you did not understand the lab or did not collect any meaningful data.
- Summary was a weak attempt that does not reflect your observations. A summary statement can not contradict your observations, even if it is contrary to what you expected.

0 0% Unacceptable

Work is unacceptable. NOT quality! Responses not relevant to the lab. Major components of the lab report are missing.

Appendix B:

Student Survey Questions

Physics has been very "hands-on," lab-based class where students have been expected to formulate questions about concepts in introductory activities before the concepts were explained in full. This is called *Inquiry Based Learning*: students first inquire and hypothesize about concepts to provide common, personal experiences with the concepts before a teacher presents a lesson. Please answer the following questions regarding this method of learning and your personal experience using the following numerical choices:

1 Never
2 Not very often.
3 Some of the time.
4 Most of the time.
5 All of the time.

1. The activities where I was expected to ask questions about a new concept helped introduce each concept better than reading the introduction in the textbook.

   1 2 3 4 5

2. The activities where I was expected to ask questions about a new concept helped introduce each concept better than hearing an introductory lecture.

   1 2 3 4 5

3. The activities where I was expected to ask questions about a new concept helped introduce each concept better than an introductory, teacher-led lab presentation.

   1 2 3 4 5

4. Creating my own questions about a new concept instead of answering pre-determined introductory questions provided by the teacher helped me take a greater personal interest in each concept.

   1 2 3 4 5

5. Creating my own introductory questions about a new concept helped me learn each concept better than if I had just listened to a lecture without this activity.

   1 2 3 4 5

6. Working with other students and hearing their intro questions about a new concept helped me take a greater personal interest in each lesson.
   1 2 3 4 5

7. Working with other students and hearing their questions about a new concept helped me learn each concept better than if I had not heard their input.

1 2 3 4 5

8. My introductory questions were addressed in the teacher's lesson.

1 2 3 4 5

9. My introductory questions were answered in the teacher's lesson.

1 2 3 4 5

10. I found the post-lesson student labs were better understood after many of our intro questions were answered and addressed.

1 2 3 4 5

11. I found many of the post-student labs to be unnecessary and redundant after our intro questions were answered and addressed in the lesson.

1 2 3 4 5

12. I found it difficult to formulate questions about each new concept without any prior information or lesson from the teacher.

1 2 3 4 5

13. I found it confusing to formulate questions and hypothesis before each new concept was explained in full.

1 2 3 4 5

14. I found it difficult to formulate questions and hypothesis about each new concept without a pre-given student intro lab to try out.

1 2 3 4 5

15. Learning with Inquiry Based Learning techniques added to my learning experience in this class.

1 2 3 4 5

Appendix C:

Student Comments

1 "I enjoyed your class a great deal this year. I am a hands on type and this class was just about all hands on. I wish we could have done even more activities this year."

2 "I believe the class has well proven points. It's a good class to take, it teaches you a lot of things that pertain to real life situations. Also you get to be active."

3 "Overall I thought this class was pretty interesting. I liked doing hands on projects, I learn much better that way. There were a few areas of this class that were difficult for me. I didn't like going into a lab or in a chapter and having to figure out everything without background information."

4 "I think this was one of the funnest [sic] classes you can take. You cover a lot of material and still do a lot of experiments to keep the students interested."

5 "This class was fun, we learned a lot of things as well I liked the way the class was hands on based, it was fun working on all the projects . . ."

6 "I would rather have been introduced to new concepts before starting labs. My reason is that when we did a lab with no background we had no way to tell whether we had done it correctly. On the other hand, when we started with a lab, I was able to derive meaning behind some of the concepts, although it was sometimes incorrect. I did enjoy the class, mostly because I like to learn hands-on rather than from the book."

7 "I would have to say that there is nothing worse than sitting in a class and listening to a boring teacher talk your ears off for an hour. I like the hand on classes and I feel that you can learn a lot more when you have something to work with in front of you. Letting the student learn his own way whether by trial & error or by introducing a new concept to him and than sitting back and seeing what the kid can do with it."

8 "Without possessing a curiosity of a particular experience you will not gain any added learning, because you will not be interested or open-minded to the learning experience. Going into a new experience with an open sense of accepting of the material will help you to gain from it. I followed this path and from that, yes, the inquiry based learning techniques did add to my learning experience. I enjoyed this class very much this year."

9 "Although most of the stuff taught this year was fairly simple, I realized I would have struggled a bit more without the labs. I got to see each concept in action. I also found that after the lab, any lecture given made complete sense. It was better than taking notes day after day, and it was more fun."

10 "I deffinatley [sic] found this way of learning to be much more different than what I am used to. So I can't say I didn't like it but I did find it personaly [sic] challenging. It is unusual to do a lab with little or no prior introduction. I must say found this teach [sic] style and class to be very interesting."

11 "I found this new way of teaching easier to use when I am told about something complex I have trouble understanding it unless I can see it and touch it so this class made it easy to understand how many things worked and helped me to understand other things not related to this class. So yes it did help me with my learning capabilities all together."

12 "Over all [sic] I would have to give out a strong High B. The class was fun and very interesting, but some of the topics got a little confusing. I wouldn't change much of anything. This is a fun informative and interesting class. I wish I could take it again."

13 "Physics was a great class that helped explain many scientific explanations that happen in everyday life. Because of this class, I can better understand how things are."

14 "I really enjoyed this class and doing all of the labs. My favorite part was physics Olympics. My grade for you is an A."

15 "Overall, I felt this was a good class. I really have no major complaints. I honestly did learn a lot from this class. I also enjoyed the hands on learning experience. Thanks for making the class enjoyable."

16 "I think this class was alot [sic] of fun. I have taken classes before where they say you will learn in a hands on way. I never have learned in a hands on way until this year. It was alot [sic] fun and I learned alot [sic] Grade A- Reason: I have never had a perfect teacher, so I do not know what one is."

17 "This class was really fun and interesting. We didn't stick just to the books, and we did different projects. I learned quite a bit about physics and I honestly enjoyed the class. Teacher rating: B+."

18 "I thought this was a very good class. I would have liked to see more of the hands stuff and demonstrations, as well as less work in that lab book, but it was still good."

19 "If I were to rate this class it would be an A. I feel that I have learned a lot over the course of the year [sic] also I thought the labs and group projects helped me to learn because you had questions you could always ask your lab partner. I would give Mr. Billings an A. He took all questions in full consideration and did the best to answer them to the best of his ability. This was a worthwhile class."

20 "This class was pretty fun. We never had homework (thanks) and the labs were easy. We always had time at the end of class. The thing that should be changed is Physics Day. It should be on a Friday. I run track and had practice but on a Friday it probably wouldn't have mattered. You as a teacher have been one of the best science teachers I have ever had. I'd give you an "A" because you explained things then let us go to work. I had fun in this class."

21 "This class over all [sic]was pretty good. I had a lot of fun in here. Though there were some times I got frustrated. Such as the bridge. [sic] The day before we had to test our bridge, it was stolen. That was a very interesting situation. I like to do hands on things rather than book work. I think I learn better that way. The best test we took was the last one, where you "didn't" just give us the answers. Over all [sic] all this class was good."

22 "I came into this class as a second choice, it seemed too easy. I think this class is more suted [sic] for freshmen or sofmores [sic]. I give the class a D. I enjoyed some of the stuff we did, cars, projects at the end. It was interesting [sic] I will give overall teaching a C+, you seam [sic] overqualifyed [sic] for this class."

23 "This class was fun. It tought [sic] me things that I never new [sic] before and I was not bored doing it. I do not learn much from lectures because I find them boring and I can not [sic] pay attention to them. Also I think to problem solve and doing a lot of hands on things allowed me to do so. I liked this class and look forward to it next year."

24 "In this physics class I not only learned from the teacher but the students. I loved group activities because it let me do certain things rather than just watching. When directions or lecture were given examples were used which game me a better understanding overall. I enjoyed this class and enjoyed how it was taught."

25 No written response

26 No written response

27 No written response

28 No written response

APPENDIX D:

Student Exploration Activities

Activity 1: The Magnitude of Air Pressure

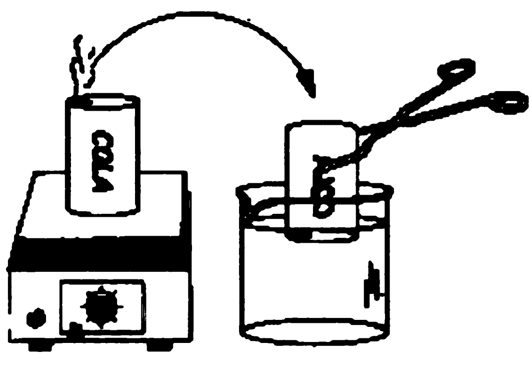
Concepts to Investigate: Definition of pressure, pressure equation, implosions, atmospheric pressure.

Materials: Balance, meter stick, soft-drink can, beaker tongs, large beaker, packing tape.

Principles & Procedures

Part 1. Shrink Wrapping a Student: What does the weight of the atmosphere feel like? To do this one person from your group will need to take off their shoes and climb into an extra large garbage bag. Sit inside the bag in such a manner that the persons head is outside of the bag. Have the person clasp the bag tightly around their neck and wait for me to come to your group with the vacuum. Observe what happens to the person inside of the bag. Be sure to be sitting on the ground!

Part 2: The collapsing can: Obtain a large beaker and fill it with water. Pour water into an aluminum soft-drink can to a depth of approximately 1 cm and place it on a hot plate until the water boils. Do not the can to boil dry. As soon as the water begins to boil, remove the can from the heat source and place it in an upright position on the tabletop. Is there any change in the can? Repeat the process, only this time invert the can and submerge the opening in the water, as illustrated in Figure E. Is there any change in the can? Draw a diagram of the experimental setup and indicate where the pressure must be highest with an H and where it must be lowest with an L.



E

When one milliliter of water boils (vaporizes) it changes into 1,000 milliliters of steam. As water in a soft drink can boils, it displaces air that was originally in the can. When the can is sealed and cooled, the steam condenses to liquid water, but now occupies only 1/1000th the volume it occupied as steam! In other words, for every milliliter of water that condenses inside the can, 999 milliliters of vacuum are left behind. The air pressure outside the can remains the same while the pressure inside drops, creating a difference in pressure that collapses the can.

Analysis:

1. On the basis of your calculations in Part 1, what is the relative magnitude of atmospheric pressure that was experienced?
2. Under what conditions does the can collapse in Part 2? Explain.
3. In the introduction to this chapter we explained why your ears "pop" when you drive up a steep mountain road. Using diagrams, explain why your ears also "pop" when you travel down the same road.
4. Airline companies pressurize the cabins of aircraft so passengers do not experience rapid changes in air pressure. On at least one occasion, however, an airplane's pressurization system failed and a passenger lost her hearing. Explain how the depressurization of the cabin may have caused this hearing loss.
5. Why may it be painful to travel into the mountains if you have a head cold?

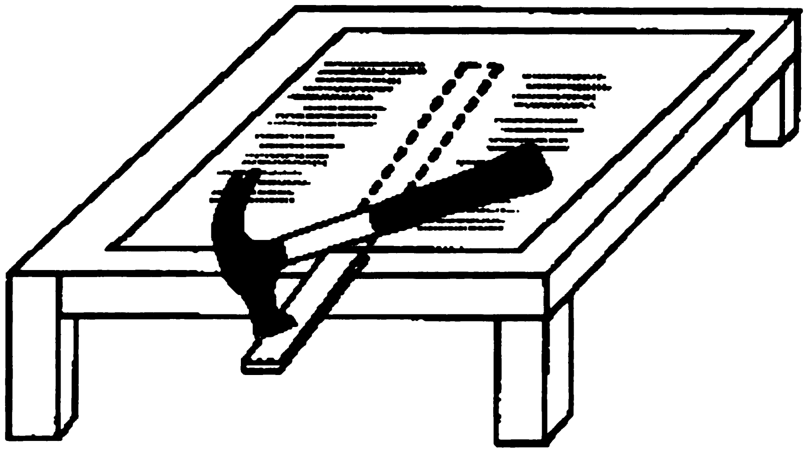
Summary:

Activity 2: The Ratio of Force per unit of Area

Concepts to Investigate: Pressure equation, force, pressure, surface area.

Materials: Newspaper, notebook paper, thin wooden slat, hammer.

Principles and Procedures: Archaeological evidence suggests that sails have been used to propel boats for more than 4,000 years. Sailing reached its height in the middle of the nineteenth century when large clipper ships such as the Sovereign of the Seas routinely traveled across the Atlantic Ocean in 15 days or less. In 1871 the British christened the H.M. Battleship Sultan, with a record 49,400 square feet of sails. For 75 years this gargantuan ship sailed the oceans of the world. Why do large boats like the Sultan require large sails? As long as the sails are exposed to the same wind, they experience identical pressure regardless of size, so what is the advantage of having large sails? See if you can answer this question after performing the following activity.



F

Pressure is the ratio of force to area p = F/A, while force is the product of pressure and area F = pA. At a given elevation, the pressure the atmosphere exerts upon objects is equal, but the force is not if the surface areas upon which the atmosphere is pressing are different sizes. Position a thin slat of wood such as a ruler or paint stirrer on a table so approximately 20 cm hangs over the edge. Place two sheets of notebook paper on the slat and press against the table until the paper is as flat as possible. Strike the overhanging portion of the slat with a hammer, as shown in Figure F. Repeat this procedure using two pieces of unfolded newspaper and record your results in the table provided. What is the magnitude of the force holding the slat down on the table in each case?

Data: Record data both qualitative and quantitave. Area papers, Atmospheric pressure (101,300 N/m^2), Force on papers, Note if the wood breaks.

Calculations: Show

Analysis:

1. Is the air pressure on a sheet of notebook paper and the newspaper the same?
2. Is the force upon them the same?
3. Did the wood break when placed under the notebook paper? When placed under the newspaper? Explain.
4. Realizing that air pressure is independent of surface area, why do large ships require large sails?

Summary:

Activity 3: Pressure Differentials - Fluid Flow Observation versus Suction

Concepts to Investigate: Pressure differentials, fluid flow, "suction."

Materials: Shallow dish, candle, matches, flask or drinking glass, hard-boiled egg, paper, Erlenmeyer flask.

Principles and Procedures

Part 1. "Suction" from candles? Light a candle and stand it upright in the middle of a pan and secure it with melted drippings. Fill the pan half full with water. While the candle is still burning, place a narrow glass or graduated cylinder over the candle. Make a sketch of what you observe. Carefully observe the base of the container, the water level in the container, and the flame. Record your observations in a sketch. When does the water level in the jar rise? Why does it rise? Indicate on your sketch where the pressure must be higher and where it must be lower to cause the results you observed.

Part 2."Suction" from burning paper? Find a flask or jar that has a mouth slightly smaller than the diameter of an egg. Peel the shell from a hard-boiled egg. Crumple a piece of notebook paper and after lighting it on fire, quickly stuff it in the flask. Immediately place the egg over the mouth of the flask and observe, paying particular attention to the egg when it is first placed on the flask. When does the egg enter the flask or bottle? Why does it enter? To remove the egg from the bottle, invert the bottle so the egg settles in the neck. Gently heat the flask with a candle or alcohol burner until the egg is forced out by expanding air. Light a second piece of paper and place it inside a flask. While holding the flask with a hot mitt, quickly place the egg in the neck and invert the bottle while holding the egg in place. Does the egg rise into the flask against gravity? Explain.

Analysis:

1. Was the water in Part 1 pushed or pulled into the bottle? Was the egg in part 2 pushed or pulled into the flask? Explain.
2. The air pressure inside the containers in Parts 1 and 2 must have been reduced to allow the water to rise. What are two factors that would lead to a reduction in air pressure?
3. Explain how a syringe withdraws blood. Draw a diagram and indicate regions of higher and lower pressure.
4. In rural areas, some people use manual lift pumps to withdraw water from wells. When the handle of the pump is depressed, a vacuum in the cylinder inside the pump is created and air pressure pushes water from the water table below, up into the cylinder, and eventually out the spout. If air pressure can lift water only to a maximum height of 10.3 meters (34 feet), how can lift pumps work when a well is greater than 34 feet deep?
5. How does a vacuum cleaner work? Draw a diagram and indicate regions of higher and lower pressure.
6. Are fluids pushed (by pressure differentials) or pulled (by "suction")?

Summary:

Activity 4: Exertion of Pressure and Force - Levitation of a Student

Concepts to investigate: Pressure and force

Materials: garbage bag, vacuum, 10 flexible straws, duct tape, & board.

Procedure:

Part I: Place a large garbage bag on a lab table and tape it down so that is air tight except for a small hole for the vacuum hose, which needs to be sealed in the bag. Place a piece of wood on top of the bag, then have a student sit on the bag, and turn on the vacuum.

Part II: Place a second bag on another lab table and proceed to tape it down, as done on part I. Instead of using a vacuum to inflate the bag, have 8 to 10 students position themselves around the bag with straws, have them puncture the bag with their straws, and seal with tape. Have a student sit op top the bag with a board underneath.

Part III (Demo): Compute the force holding two Magdenberge disks together. The famous "Magdeburg hemispheres" experiment of 1654 demonstrated the enormous strength of atmospheric pressure. Two teams of horses couldn't pull them apart. Why were the hemispheres held together? By what? Team up with other students and see if you can pull the hemispheres apart.

Observations:

Record your qualitative observations.
Record the mass of the person and the area of the board.
Record the diameter of hemisphere and compute the cross-sectional area in square inches. (Area $=\pi r^2$)

Analysis:

1. Calculate the amount of pressure exerted by the person sitting on the board. (P=F/A)
2. Calculate the force in pounds pushing the disks together. (F = P x A) Please show all your work. Assume that the air pressure is 14.7 lb/in (equivalently 105N/.m2) and for simplicity that the two disks are completely evacuated to a perfect vacuum.

Summary:

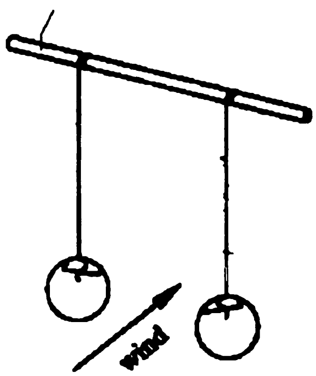
Activity 5: Bernoulli's Principle

Concepts to Investigate: Bernoulli's principle, manometer, atomizers, pressure differential.

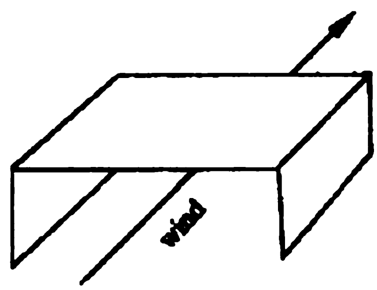
Materials: Table-tennis balls, thread, tape, paper, straw, food coloring.

Principles and Procedures

Part 1. Air stream between two objects: Use tape to attach a piece of thread to each of two table-tennis balls and suspend them as shown in Figure C. Use a straw to blow between the two table-tennis balls and note the movement of each. On Figure C indicate the new positions of the balls and the regions of lower and higher pressure. On the same diagram indicate where one must blow so the table-tennis balls move in opposite directions. Try it. Once again indicate where the regions of lower and higher pressure must be and the direction of the net force on each ball.



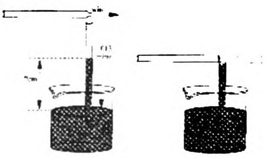
C



D

Fold a sheet of notebook paper in half lengthwise and then fold down the ends as shown in Figure D to make a paper bridge. What do you think will happen if you place the "bridge" on your desktop and then blow under it? Try it and indicate on the diagram the regions of higher and lower pressure and indicate with an arrow the net force on the bridge.

Part 2. Measuring pressure with a straw-manometer: Will the level of water in the straw illustrated in Figure E change if you blow across its tip using another straw as shown? Try it. Was your prediction correct? Indicate on the diagram where the regions of lower and higher pressure must be to cause this result. Squeeze the tip of the horizontal straw and try it again. Is the result more pronounced? Why or why not?



E F

When you are not blowing, the air pressure is the same (approximately 1,013 millibars} above the water in the straw and above the water in the beaker because both are open to the atmosphere. When you blow, air pressure above the straw decreases while air pressure above the water in the glass remains constant. You can determine the reduction in pressure by measuring the height of the water in the straw. Every centimeter the water rises represents a reduction of one millibar (about 0.01percent of normal atmospheric pressure). If, for example, water rose 10 centimeters, you could conclude that air pressure above the straw decreased by approximately 10 mbar. Determine how high the water will rise in the straw and calculate the accompanying air pressure above the straw. Compare your value to the class average. As a point of comparison, the air pressure on top of Mount Everest, the highest mountain in the world, is only about 340 mbar!

Part 3. Atomizer: Homeowners and gardeners spray fertilizers or pesticides on lawns and gardens using a sprayer attached to the end of a hose. As water is forced through a narrow point in the nozzle, pressure decreases and fertilizer or pesticide is drawn through a side arm from the bottle into the stream of water. You can make your own "atomizer" or garden sprayer simply by shortening the straw used in Part 2 so fluid rises to the top of the straw when blowing across its open end. Place a few drops of food coloring in a beaker and then use your atomizer to spray a mist of the colored water onto a sheet of white paper (Figure F).

Observations and Data:

Record all observations.

	Height of Water In Straw (cm)	Reduction in Air Pressure (mbar)	Air pressure Above Straw (mbar)
No Wind			1,013
Maximum height			
Class average			

Analysis:

1. Given only two straws, how can you separate the suspended table-tennis balls without blowing on them? Explain.
2. Evaluate this statement: "The table-tennis balls in part 1 were attracted to each other."
3. The reduction in fluid pressure is proportional to the square of the speed of the fluid. On the basis of this relationship, how much higher would water move in straw if the velocity of the air across the top doubled?
4. How could you employ Bernoulli's principle to develop an anemometer, a device used to measure wind speed?
5. What are some devices that use Bernoulli's principle to atomize (to reduce into small particles) and spray a liquid?
6. Hurricanes and tornadoes may cause houses to explode. Explain.
7. Why is it dangerous to stand near a fast moving train?
8. Ships that pass close to each other run the risk of sideways collision. Explain.

Summary:

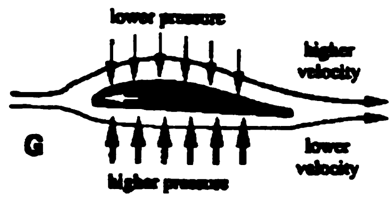
Activity 6: Fluids:Gases & Lift

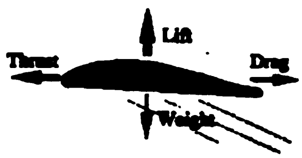
Concepts to Investigate: Lift, airfoil, flight, Bernoulli's principle, hydrofoil.

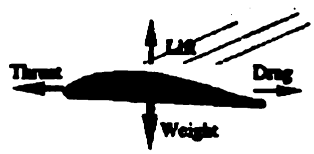
Materials: Pencil, paper, tape, 3" x 5" card, straight pin, funnel, straw, tubing, table-tennis ball.

Principles and Procedures: On November 2, 1947, industrialist Howard Hughes piloted a flying boat by the name of Spruce Goose to a height of 70 feet on a 3,000-foot test run in Long Beach Harbor, California. Although it never flew again, the 212-ton aircraft set the record as the largest and heaviest aircraft ever to fly. Newton's second law states that an object will accelerate only if there is a net force acting upon it. To fly, the Spruce Goose required a lifting force in excess of its 212-ton weight. How was such a force generated?

According to Bernoulli, fluid pressure decreases as speed increases. If a fluid travels more rapidly across the top of a wing than the bottom, the wing will experience a lifting force because the pressure on top will be less than the pressure on the bottom. An examination of the wings of birds and airplanes shows they have greater curvature on the top than on the bottom (Figure G). The relative speed of air moving over the wing is greater than the speed of air moving under the wing because it must travel a greater distance in the same length of time. Thus the pressure on top is less than the pressure on the bottom, creating a lifting force. If the lifting force is greater than the weight of the plane, the plane will climb (Figure H), but if the weight is greater than the lifting force, the plane will descend (Figure I).

G


H


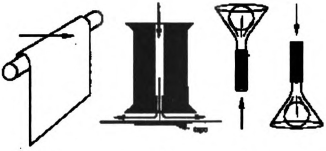


I

Part 1. Airfoil: Wings, rudders, and propeller blades are examples of airfoils, surfaces used to control the speed and direction of aircraft. In this activity you will examine the principle of lift as it applies to airfoils. Trim a piece of notebook paper to a width slightly less than the length of your pencil. Tape the paper to the pencil as illustrated and blow across the top surface of the paper (Figure I). Explain movement of the paper in terms of Bernoulli's principle. Draw a diagram of the airfoil and indicate regions of higher and lower pressure.

Part 2. Airstream: Cut a seven-cm square from a sheet of heavy paper or thin cardboard. Determine the center of the card by drawing diagonal lines and marking the point of intersection. Place a straight pen through the card at this point and tape its head to the card, as shown in Figure K. Place the tip in the end of a spool of thread, gently hold the card against the spool, and blow through the center of the spool. Remove your hand and report your observations. Explain the results in terms of Bernoulli's principle. Indicate on Figure K the regions of higher and lower pressure.

Part 3. **Float valve**: Cut a small section of drinking straw and connect it to a funnel, as shown in Figure L. You may need to use a piece of rubber tubing to connect the straw to the funnel. (The only reason for the straw is to ensure sanitation. Never touch your mouth directly to laboratory glassware as it may be contaminated.) Place a table-tennis ball in an upright funnel, tilt your head back, and blow steadily. Does the ball fly out or remain in the funnel? Now point the funnel down (Figure M), hold the table-tennis ball in the funnel, blow steadily through the funnel, and slowly remove your hand. Repeat until the ball remains in the inverted funnel while you are blowing. On Figure M indicate regions of lower and higher pressure and the direction of the resultant force upon the ball.



J K L M

Observations & Data:

Analysis:

1. What is the relationship between the speed of air across the paper and the amount of lift in part 1?
2. Does it become easier or more difficult to remove the table-tennis ball from the funnel as the wind speed increases? Explain.
3. The table-tennis ball in Part 3 acts like a valve. Is it a one-way or a two-way valve? Explain.
4. Some race cars have elevated inverted wing like structures known as spoilers (Figure N). What effect may such spoilers have on a racecar's performance?

N

5. A hydrofoil is a boat that uses submerged wings (also known as hydrofoils) to raise the hull out of the water when traveling at high speeds. Sketch your own design for such a boat and explain how it functions.

Summary:

Activity 7: Streamlines and Air Drag

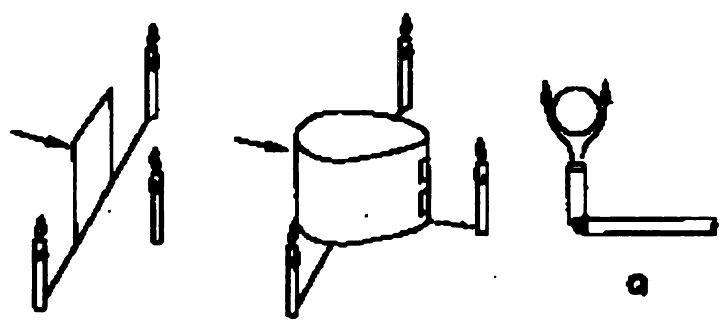
Concepts to Investigate: Streamlines, air drag, stability, Bernoulli's principle.

Materials: Paper, tape, candles, flexible straw, table-tennis ball.

Principles and Procedures: In 1934, Chrysler Corporation introduced the "Airflow," one of the first automobiles to feature a streamlined aerodynamic design. Today, auto manufacturers routinely use wind tunnels to study airflow patterns over cars in an effort to minimize air resistance or drag. A streamlined design is one that provides a smooth, non-turbulent flow of air across the surface of the vehicle.

Part 1. Air drag: Cut a note card into a 5-cm square and place lighted candles in front of it and to the sides, as shown in Figure 0. Blow toward the card, and note which way each of the flames bend. Cut a piece of notebook paper into a rectangle 5 cm wide by 28 cm long, shape into a teardrop as illustrated in Figure P, and tape the ends. The widest portion of the "teardrop" should be 5 centimeters. Blow toward the paper and once again record the directions the flames move. Indicate on Figure p the regions of lower and higher pressure and the direction of the net force upon each flame. (Force is equal to the pressure multiplied by the surface area on which the pressure acts.) Does the flame behind the barriers move the same direction in both cases? Explain.

Part 2. Balancing a ball in air: A streamline is the line a fluid particle follows as it flows. If an automobile is "streamlined," air molecules follow predictable streamlines as they flow over the surface of the car. If the car is not streamlined, air particles may flow in an unpredictable turbulent manner. You may have noticed people driving on a highway with a sofa or mattress strapped to the top of their car. Such objects cause turbulent airflow and reduce the stability of the vehicle. A passenger in a car carrying such a load may notice the car jerk erratically as it moves down the highway. The following investigation will help you understand stability.



O P Q

Bend a flexible straw as shown in Figure Q. Take a deep breath and blow a slow, steady stream of air through the straw. Gently release the table-tennis ball over the stream of air and record the length of time you can keep it suspended. With a little experience you should be able to keep it aloft for five seconds or more. Repeat the process using a wad of paper of similar size and mass. Which is easier to keep aloft? Which object is more streamlined and stable?

Observations & Data:

Analysis:

1. Use Bernoulli's principle to explain why the flames bend in different directions depending on the type of barrier.
2. Explain why some freight trucks have large fiberglass or metal "bubbles" on top of the cab.
3. Is it easier to keep a table-tennis ball or a wad of paper aloft in Part 2? Which object is more streamlined?
4. Use Bernoulli's principle to explain how the ball can be balanced in midair.

Summary:

Activity 8: How Does Water Pressure Vary with Depth?

Concepts to Investigate: Pressure, water pressure and depth, pressure and fluid flow, Pascal's principle, fluid pressure, transmission of pressure in closed containers.

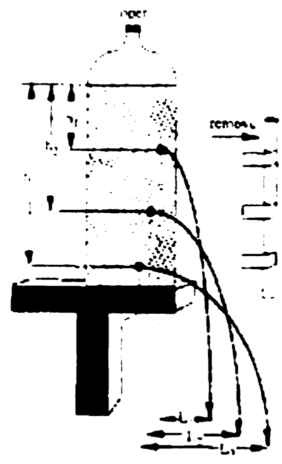
Materials: Two-liter soft-drink container, tape, pencil or glass rod, ruler, pliers, nail, burner, large pan, Small funnel or thistle tube, rubber tubing, glass U-tube, balloon.

Principles and Procedures: You may have felt pain or pressure in your ears when swimming near the bottom of a deep pool, but not when swimming near the surface. The pain you experience in deep water results from the pressure water exerts on your eardrums. Water pressure increases with depth according to the equation:

$$P_{(fluid)} = \rho g h$$

Where ρ is the density of the fluid, g is the acceleration due to gravity, and h is the height of the water column above the point in question. Since the density of water is constant ($\rho = 1\ g/cm^3$) and the acceleration due to gravity at Earth's surface is constant ($g = 9.8\ m/s^2$), the only variable is depth. Thus, fluid pressure is directly proportional to depth.

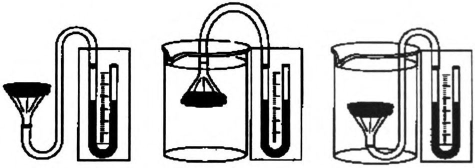
Part I: Pressure as a Function of Depth. This can be tested using the apparatus shown in Figure E.



E

Obtain a clear two-liter soft-drink container. While holding the head of a nail with pliers, heat the tip in the flame of a Bunsen burner and then use it to melt three holes of equal diameter in the container, as shown in Figure E. The holes should be slightly offset from each other as illustrated. Wrap the ends of three pieces of tape around a rod so they are spaced the same distance from one another as the holes in the container. Place the other ends of the tape over the holes. Fill the container with water, leave it uncapped, and mark the water level on the bottle. Measure the distance from the water level to each hole and record these in the table as h_1, h_2, and h_3. The initial pressure may be calculated using the equation $P = \rho gh$. To quickly calculate the pressure (measured in PASCAL's) multiply the depth (h, measured in centimeters) by 98 Pa/cm. Place the bottle at least one meter above a pan. Pull the rod away from the bottle so all three holes are opened simultaneously and record the maximum horizontal distance each stream of water moves before reaching the pan. From your data, does it appear as though the relationship between fluid depth and fluid pressure $P = \rho gh$ is valid? Explain.

Part II: Transmission of Pressure within a Fluid. Pascal's principle states that fluids exert pressures equally in all directions. Thus, a diver experiences as much pressure from the water beneath her as from the water above her. In this investigation you will develop a pressure gauge to determine if water pressure is non-directional. Construct a U-tube by bending a section of glass tubing as illustrated in Figure F. Alternatively, you may use two straight pieces of glass connected by an arc of flexible tubing. Add water to the U-tube until it is approximately half-full. Measure the height of the water in both arms and record in the table. Using a pair of scissors cut a section from a large balloon big enough to fit over the opening of a small funnel or thistle tube. Stretch the material over the opening and secure it with rubber bands if necessary. Connect tubing to the end of the funnel and one end of the U-tube. Immerse the funnel in water and record any changes in the level of the water in the U-tube (Figure G). A rise in the column of water on the open side of the U-tube indicates an increase in pressure on the funnel membrane. Carefully measure the change in height within the tube and record it in the table. Invert the funnel, keeping the membrane at the same level, but facing the reverse direction. Again record the height of the water column (FigureH). Repeat the procedure, holding the funnel horizontally so that the middle of the funnel is at the same level. After completing three measurements at the same level, move the funnel deeper and take three additional measurements. What is the influence of depth on pressure? On the basis of your data, is fluid pressure directional? (Is pressure greater in one direction than another?)



F G H

Observations & Data:

Part I : (Record location of hole, Depth, Initial Pressure (Pa), and Length of Water Stream)

Part II: (Record depth (cm), Orientation up – down- horizontal, Height Gain of Water Column (cm) –for three different depths)

Analysis:

1. Does your data validate the pressure equation: $P = \rho gh$? Explain.
2. Describe what would happen to a strong, flexible volleyball if you released it from a submarine at the bottom of the ocean.
3. Is your data consistent with Pascal's principle?
4. The Mariana's Trench is the deepest known portion of the Earth's surface, with a maximum depth of 11,034 m (36,201 ft). In 1960, Jaques Piccard and Don Walsh descended to a depth of 10,912 m (35,800 ft) in the bathyscaph Trieste. Use the pressure equation to determine the approximate pressure in kiloPascals (1 Pascal = 1 newton/m^2 = 1 kg/ms^2) experienced by the bathyscaph at this depth. Assume that ocean water has a density of 1 g/cm^3 and that density does not vary with depth. How many times greater is the pressure at this depth than at the surface?

Summary:

Activity 9: Archimedes' Principle

Concepts to Investigate: Archimedes' principle, displacement.

Materials: Aluminum foil and scissors, water

Principles and Procedures: The Netherlands is a tiny nation in Northern Europe. Due to a shortage of land, the Dutch have made great efforts to reclaim some of the shallow coastal waters for agricultural purposes. The Zuider Zee project, completed in 1932, reclaimed 200,000 hectares (500,000 acres) of land from the sea by the use of massive sea dikes. These walls are constructed of concrete blocks shaped like boats, which were floated into position and then sunk by opening holes in the bottoms. According to Archimedes' principle, an object will float when it displaces a weight of water equal to its own weight. Many people find it surprising that some commercial boats are made of concrete. Yet even concrete, like steel, will float if shaped appropriately, as the Dutch have shown.

A flat piece of heavy-gauge sheet metal will sink because its weight exceeds the buoyant force. If, however, the metal is bent it will displace more water and be subject to a greater buoyant (upward) force. Using aluminum foil, build and test your own aluminum-foil boat.

Observations & Data: Make a sketch of your boats design.

Analysis:

1. Using Archimedes' principle, explain why your boat will sink if placed on its side.
2. Explain how concrete boats are able to float.
3. The density of lead is 11.3 times the density of water. How would you modify the design of your boat if it were made of lead?

Summary:

Activity 10: Regulation of Buoyancy

Concepts to Investigate: Buoyancy, neutral buoyancy, ballast, swim bladders, Cartesian diver.

Materials: Eyedropper, permanent marker, 2-liter flexible soft-drink container.

Principles and Procedures: If you observe fish in an aquarium, they appear to maintain constant depth with virtually no effort. By contrast, you must support a bowling ball to keep it from sinking and must restrain a basketball under water to keep it from rising to the surface. If an object remains suspended in a fluid, there is no net force on that object-the force of gravity is countered by an equal and opposite buoyant force. This condition of "weightlessness" is known as "neutral buoyancy."

Approximately 50 percent of all species of fish maintain neutral buoyancy through use of a swim bladder, a gas-filled sac located in the upper portion of the body cavity. The gas in the bladder helps to establish neutral buoyancy by countering the heavier tissues of the fish. By regulating the amount of gas in the bladder, fish can regulate their buoyancy and the depth at which they remain while resting. In this activity you will make a device known as a Cartesian diver to study the principles of buoyancy.

Use a permanent fine-tipped marker to draw a scale on an eyedropper in 5-milimeter increments. Fill approximately one fourth to one third of the eyedropper with water and place it in a flexible, plastic soft-drink container that is completely filled with water. Once the eyedropper is floating with its tip down, seal the container and measure the height of the water in the eyedropper. Squeeze the walls of the container and watch the eyedropper descend. If the eyedropper sinks before pressure is applied, there is too much water in the dropper. If it does not descend when pressure is applied to the container, there is not sufficient water in the dropper. Record the height of the water in the eyedropper when it is at the bottom and when it is suspended in the middle, and compare these values with the height when it is floating on the surface. According to Archimedes' principle, the eyedropper is buoyed up be a force equivalent to the weight of the water it displaces.

Observations & Data:

Analysis:

1. Explain why the "diver" descends when pressure is applied to the system.
2. Is more or less water displaced when the "diver" is on bottom? Explain.
3. How might a submarine regulate its depth?
4. The National Aeronautics and Space Administration (NASA) requires astronauts in training to have experience in a weightless environment. How might such an environment be simulated here on Earth? Explain.

Summary:

Activity 11: Buoyancy and Newton's Law of Interaction- Commerce Fraud?

Concepts to Investigate: Buoyancy, Newton's third law (law of interaction), weight.

Materials: Beaker, balance, spring scale, metal object.

Principles and Procedures: In some areas of the world, expensive liquids such as natural oils and perfumes are sold by weight in open-air markets and bazaars. Suppose a customer orders 1 kg of kiwi-seed oil, and the vendor weighs it, stirring the liquid with a spoon while adjusting the balance. The customer complains that the spoon is making the weight of the oil appear larger than it really is, while the vendor defends himself by showing that he is supporting the spoon and claims it therefore can't add weight to the pot. Newton's third law states that if one object exerts a force upon a second object, the second object exerts a force of equal magnitude but opposite direction on the first object. On the basis of Newton's third law, do you think the vendor is cheating the customer? Perform the following activity to find out.

Determine the weight of a beaker two thirds full of water and record in a data table. Suspend a metal mass from a spring scale and record its weight. Submerge the weight in the middle of the beaker, being careful not to allow the mass to touch the side or bottom of the beaker. Again measure the weight of the beaker and hanging metal object. Analyze your results and determine if the customer or the vendor was correct.

Observations & Data:

Analysis:

1. Does the weight of the beaker increase, decrease, or remain the same as the objects are submerged?
2. Does the weight of the metal object increase, decrease, or remain the same as it is submerged? Explain.

Summary:

Was the vendor cheating the customer? Explain based upon your observations.

Activity 12: Fluid Density and Buoyancy

Concepts to Investigate: Density, buoyancy, Archimedes' principle.

Materials: Salt, eggs, beakers.

Principles and Procedures: Salmon are one of the most economically important fish of the Pacific Northwest. They spend much of their lives in the ocean, but swim up major rivers to spawn. When swimming from the ocean into rivers, will salmon find the water more or less buoyant? Major cargo ships sail up the Saint Lawrence Seaway from the Atlantic Ocean to the Great Lakes. If their ballast tanks are not adjusted, will the ships ride higher or lower when they move from the ocean to the freshwater seaway? To answer these questions we first need to determine if the density of a fluid affects the buoyancy of objects immersed in it.

Density is the mass to volume ratio of a substance. If the density of an object is less than the density of the fluid in which it is placed, the object will float. If the density of the object is greater than the density of the fluid, it will sink. Because of the presence of dissolved salts, salt water has greater density than freshwater. Archimedes' principle states that an object is buoyed by a force equivalent to the weight of the water it displaces. Knowing this, what will happen to a ship or fish as it moves from salt water to fresh water or vice versa?

Place a fresh egg in a beaker of tap water and record its position. Slowly stir salt into the beaker until the egg rises and is suspended above the bottom of the beaker but below the surface of the water. What should be added to raise the egg to the surface? What should be added to cause the egg to sink to the bottom once again? Try it.

Observations & Data: Make a sketch of the before and after.

Analysis:

1. Should more solute (salt) or solvent (water) be added to raise a submerged egg to the surface?
2. What should be added to cause the egg to sink? Explain.
3. Why did the egg rise when salt was added to the system?
4. Will a ship ride higher in an ocean or a lake?
5. Icebergs pose a threat to navigation because the majority of their mass is submerged and hidden from view. Will more or less of an iceberg be submerged if it is floating in fresh water.
6. Petroleum geologists and engineers often flood oil wells with salt water to increase production. Why?

Summary:

Activity 13: Surface Tension - Shapes of Droplets

Purpose: Make general observation. Examine and sketch the shapes of the following conditions, please note the angle of contact:

Part I: Drops forming on a dripping faucet.

Part II: Pools of liquid on various surfaces

water on clean glass, water on waxed glass & mercury on glass

Part III: Family of Drops on a table. (about 8 drops)

Analysis:
1. A tiny raindrop resting on a wooly sleeve is spherical, but a large drop of water on a waxed floor takes a flatter shape. Why?
2. What do your observations show about liquid surfaces?

Summary:

Activity 14: Surface Tension - Cohesion & Adhesion Forces

Concepts to Investigate:

Materials: Glass or plastic cup, cork, water, liquid detergent, pennies

Part I: Cork Flotation. Fill a glass halfway with water and float a small cork on the center of the water surface and observe. Record your observations in the form of a sketch. Add more water to the glass until it is filled to the brim. Observe where the cork now floats. Record. Gently push the cork to the edge and record your answers.

Part II: How many Pennies? Teacher Demo: Place one glass on the table and fill it to the brim (not too overfull, just full). Have the students predict how many pennies can be put into the glass before it overflows. Record their predictions. Start putting pennies in the glass of water, very carefully with the edge first (vertically) until the water overflows. Record the amount of pennies that you added until it spilled. Students repeat the above experiment; predict the number of pennies that the cup can hold and the actual amount that it held:

Observations:

Analysis:

Part I:

1. Why is the cork moving towards and sticking to the side of the glass (with the glass half-filled)?
2. Where is the water level the highest in the half-filled glass?
3. Why is the cork floating in the center of the full glass?
4. Where is the water level highest in the full glass?
5. Why can we fill the glass more than full without overflowing the water?

Part II:

6. How many pennies could go in the first glass (teacher's)? In the second (student's)?
7. What made the water overflow so easily in the student run of the experiment?
8. What kept the water from overflowing in first glass?
9. What shape did the meniscus take in the first glass?
10. How would the number of coins compare if we used dimes instead of pennies? Nickels instead of pennies.

Summary:

Activity 15: Surface Tension - Surface Tension & Cohesive Forces

Concepts to investigate: Surface tension & cohesive force

Materials: beaker, whole and ground pepper, Liquid detergent & dropper, 3 x 5 card, shallow tray.

Procedure:

Part I: Pepper Float. Fill the beaker with water. Predict whether a whole pepper kernel will sink or float in the water. Record your prediction. Drop the kernel into the water, observe and record what happens. Shake some ground pepper on the water surface, record your observations. Using the dropper, place a drop of detergent in the water and observe what happens to the fine pepper.

Part II: The Detergent Propelled Boat. Fill a shallow tray with water. Cut out a boat from the index card as shown in class. Let the paper float on the water towards the edge of the tray. Place a small drop of detergent in the center opening of the boat. Record your observations.

Observations:

Analysis:

Part I:

1. Why did the same pepper in the fine state float on the water?
2. Do you think that the pepper has a higher or lower density than water?
3. Did the density of the pepper change by grinding it?
4. What did the detergent do to the water surface?
5. What forces were weakened between the water molecules when the detergent was added?

Part II:

6. Why does the paper boat move forward only when the soap touches the water?
7. What made the paper boat be pulled forward?
8. What did the detergent do to the cohesive forces between water molecules?
9. Would this work without a hole in the paper boat?
10. What would happed if we touched the soap to the side of the boat?

Summary:

Activity 16: Surface Tension
Concepts to Investigate: Surface Tension

Materials: Two regular identical drinking glasses, an index card, paper clips and a dime.

Principles & Procedures: In the body of a liquid, the attractive forces between molecules act in all directions. However, at the surface, the act only inward. This forms a surface "skin", and the attraction between molecules in the surface pulls inward to hold the liquid together much like a drop.

Part I: Water Filled Cups. Fill the two glasses with water to the brim. Place the index card on one of them and turn the glass upside down while holding the card against the glass. Let go of the card, place the inverted glass on the other water filled glass, and slip the card out carefully (keeping the top glass exactly over the bottom glass). Place a paper towel around the bottom glass to guard eventual spillage. Examine the set up and try to determine if anything could be added to these two cups without spilling. Record your analysis. Taking the dime, push it between the two glasses and slip it inside the glasses while holding the top glass. Record your observation.

Part II: Paper Clip Float. Bend one paper clip as shown in class and lay the other regular one across it. Fill a cup with water. Slowly, lower the clips into the water, if done carefully enough, and provided that the clip is perfectly flat, it will float. Rubbing the clip on the side of one's nose, to grease it, helps repel the water. The way the clip lies on the surface "skin" should be clear to observe. Record your observations. Sometimes one or two clips will have to be tried, until one works, because of sharp edges.

Part III: Surface Tension in a Liquid Stream. Poke three small holes in the side of a styrofoam cup, as close together and near the bottom as possible.
Observations:

Analysis:

Part I:
1. Why did the water not run out while the dime was being slipped in?
2. Did any water spill while the coin was being pushed in?
3. What indicated that some water must have run out?
4. What other objects could have been slipped inside the glass?

Part II:
5. Why must you lay the clip gently on the surface?
6. Why would an aluminum clip work better than a steel one?

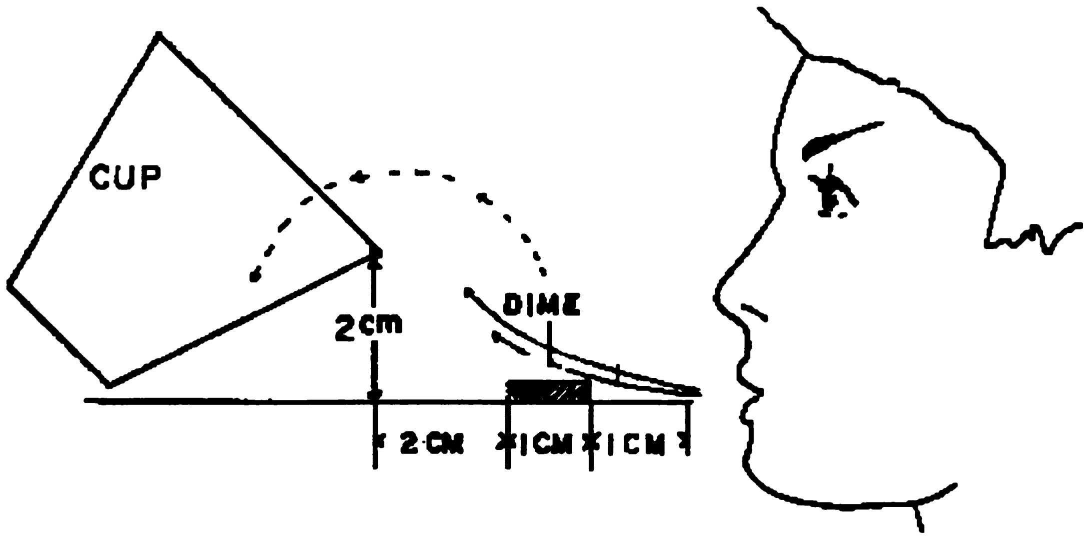
APPENDIX E:

Student Laboratory Experiments

Lab 1: Levitation of Coins and Blown "Wind" Velocities

Concept to investigate: Attempt to get a dime off a table into a cup on the table without touching the coin.

Principles & Procedure: The cup must be shallow, or tilted so that the lip is about 2 cm off the top of the table, and about 2-3 cm from the edge of the table, as shown. It looks impossible for the dime to get into the cup, but if you blow hard and suddenly, parallel to the tabletop, the dime should hop in.



Mathematical Analysis: Bernoulli's principle states that the pressure differential, ρ, between the top and bottom of the dime is given by :

$$P = 1/2\rho v^2$$

where ρ is the density of air (1 Kg/m^3) and v is the velocity of the air blown over the dime. Now, the area of the dime, A is ($2.5x10^{-4}m$) multiplied by this pressure differential must equal the gravitational attraction on the dime, mg, if it is to rise off the table. Since the mass of the dime is 2.24 gm, the gravitational force is about 0.0224N.

$$\text{So: } F = PxA$$

$$\text{Where } F = mg, \; A = \text{area, ad } P = 1/2\rho v^2$$

$$\text{So: } mg = A \text{ x } 1/2\rho v^2$$

Isolate and solve for v,

$$v = \sqrt{(2mg/A\rho)}$$

1. Calculate the "wind" velocity over the dime in terms of m/s, km/h, mph.
2. Calculate the "wind velocity over which a quarter may be levitated.

Summary:

Lab 2: Calculating Buoyant Force

Concepts to Investigate: Determining buoyant force, buoyancy of different materials, water displacement.

Materials: Beaker, spring balance, graduated cylinder or other container, metal and wooden weights of equal mass.
500-mL beaker 500-g hooked mass polystyrene cup, 5-N. capacity or greater 100-g hooked mass, paper towel

Part I: Principles and Procedures: Archimedes' principle states that the buoyant force is equal to the weight of the fluid displaced or pushed aside by an object. Thus, the weight of a submerged object should be less than its weight in air by an amount equal to the weight of the water it displaces. Perform the following investigation to see if this is correct. Suspend a metal object in air from a spring balance and record its weight in the table (1 kg weighs 9.8 N; 1 g weighs 0.0098 N). Fill a beaker with water until it overflows. Once water has stopped flowing, place a dry graduated cylinder or other container beneath the spout of the beaker. Hang the object from the scale and slowly immerse it in the beaker such that all of the displaced water flows over the spout and into the graduated cylinder. Record the new weight of the submerged object. The weight of water displaced can be measured by collecting and weighing all the water that overflows from the beaker. You can determine the weight of water simply by measuring the volume in a graduated cylinder. The volume in milliliters will be the same as the mass in grams since the mass of one milliliter of water is one gram (the density of water is 1 g/ml). Repeat the activity with a block of wood of equal mass. Analyze the results recorded in the table. Is the weight of the displaced water equal to the difference in the weight of the object when measured in air in water?

Observations & Data: Table needs to include weight in air, weight in water, difference in weight, weight of water displaced - for both the metal and wood object.

Part II: Principles & Procedures: Floating & Displacement. Archimedes' principle states that an object wholly or partially immersed in a fluid is buoyed up by a net force equal to the weight of the fluid that it displaces, $F_{buoyant} = F_{weight\ of\ fluid\ displaced}$.
Recall that $F_{weight\ of\ fluid\ displaced} = \rho_{fluid} V_{fluid\ displaced}\, g$, where ρ = density. When an object with a density less than that of the fluid is submerged, it will sink only until it displaces a volume of fluid with a weight equal to the weight of the object. At this time, the object is floating underwater, equilibrium exists, and $\rho_{fluid} V_{fluid\ displaced} = \rho_{object} V_{object}$.

If the density of an object is greater than that of the fluid, an upward buoyant force from the pressure of the fluid will act on the object, but the magnitude of the buoyant force will be too small to balance the downward weight force of the denser material. While the object will sink, its apparent weight decreases by an amount equivalent to the buoyant force. In this experiment, you will investigate the buoyant force of water acting on an object. Recall that 1 mL of water has a mass of 1 g and a weight of approximately 0.01 N. The buoyant force acting on the object is determined by finding the difference between the weight of the object in air and the weight of the object when it is immersed in water and is given by the following equation:

$$F_{buoyant} = F_{weight\ of\ mass\ in\ air} - F_{weight\ of\ mass\ in\ water}.$$

Pour cool tap water into the 5OO-mL beaker to the 3OO-mL mark. Carefully read the volume from the gradations on the beaker and record this value in Table 2. Hang the 5OO-g mass from the spring scale. Measure the weight of the mass in air and record this value in Table 2. Immerse the 5OO-g mass, suspended from the spring scale, in the water. Do not let the mass rest on the bottom of the beaker or touch the sides of the beaker and keep it suspended from the spring scale. Measure the weight of the immersed mass and record this value in Table 2. Measure the volume of the water with the mass immersed. Record the new volume reading in Table 2. Remove the 5OO-g mass from the beaker and set it aside.

Measure and record in Table 3 the volume of water in the beaker. Place the 1OO-g mass in the beaker of water. Measure and record in Table 3 the volume of the water in the beaker with the mass immersed. The polystyrene cup will serve as a "boat." Remove the mass from the water, *dry* it with a paper towel, and place it in the polystyrene cup. Float the cup in the beaker of water. Measure and record in Table 3 the new volume of water.

Observations & Data: Table 2 record weight of 500- gram mass in air, immersed n water, initial volume of water in beaker, volume if water in beaker with the 500 gram mass immersed. In table 3 record the volume of water in beaker, volume of water with 100 g immersed, Volume of water with 100-g mass in a polystyrene cup.

Analysis:

1. What is the buoyant force on the metal and wood objects in this activity? Explain.
2. What was the weight of the wood when resting in the water? Explain.
3. Would an object weigh more or less if there were no atmosphere on Earth? Explain.
4. If a block of metal and a block of wood of identical mass were submerged, would the buoyant force on both be the same? Why or why not?
5. An average-sized adult human has a volume of approximately 68,000 cm3. If air weighs approximately 1 Newton per cubic meter, what is the buoyant force of the atmosphere on such an individual?
6. Calculate the buoyant force of water acting on the 500-g mass. Show all work!
7. Using values from Table 2, calculate the volume of water displaced by the 500-g mass. Calculate the weight of the water displaced. Compare the weight if the volume of water displaced with the buoyant force acting on the immersed object that you

calculated in question #6. If the values are different, describe some sources of error to account for this difference. (DO NOT LIST HUMAN ERROR)

8. What happened to the water level in the beaker when the 100-g mass was placed in the polystyrene cup (boat)? Propose an explanation, which includes density, for any difference in the volume you found during your observations.
9. Two people floating on an inflatable raft in a swimming pool. What happens to the water level in the pool if both fall off the raft and into the water?

Summary:

APPENDIX F:

Sample Student Exercise Sets

Exercise Set 1

1. (A) What is the energy source for the motion of gases in the atmosphere? (B) What prevents atmospheric gases from flying off into space?
2. How does the density of gases at different elevations in the atmosphere differ from the density of liquids at different depths?
3. What causes atmospheric pressure?
4. What is the mass of a cubic meter of air at 20°C at sea level?
5. What is the mass of a column of air that has a cross-sectional area of 1 square centimeter and that extends from sea level to the top of the atmosphere? b. What is the weight of this air column? c. What is the pressure at the bottom of this column?
6. How does the pressure at the bottom of the 76-cm column of mercury in a barometer compare with the pressure due to the weight of the atmosphere?
7. When you drink liquid through a straw, it is more accurate to say the liquid is pushed up the straw rather than sucked up the straw. What exactly does the pushing? Explain.
8. Why will a vacuum pump not operate for a well that is deeper than 10.3 m?
9. The atmosphere does not ordinarily crush cans. Yet it will crush a can after it has been heated, capped, and cooled. Why?
10. Why can an aneroid barometer be used to measure altitude?
11. When air is compressed, what happens to its density

Exercise Set 2

1. When the speed of a fluid flowing in a horizontal pipe increases, what happens to the internal pressure in the fluid?
2. What are streamlines? Is the pressure greater or less in regions where streamlines are crowded?
3. Does Bernoulli's principle provide a complete explanation for wing lift, or is there some other significant factor?
4. Why does a spinning ball curve in flight?
5. Fill a bottle with water and hold it partially under water so that its mouth is beneath the surface. Why does the water not run out? How tall would the bottle have to be before water ran out? (Hint: You can't do this indoors unless you have a ceiling 10.3 m high!)
6. The "height" of the atmosphere is about 30 km. The radius of the earth is 6400 km. What percentage of the earth's radius is the height of the atmosphere? 0.47%
7. Make a calculated estimate of the weight of air in your classroom. (Floor area x ceiling ht)
8. Relative to sea level, would it be slightly more difficult or somewhat easier to drink via a straw at the bottom of a deep mine? At the top of a high mountain? Explain.
9. If there were a liquid twice as dense as mercury, and if it were used to make a barometer, how tall would the column be?
10. Small bubbles of air are released by a scuba diver deep in the water. As the bubbles rise, do they become larger, smaller, or stay about the same size? Explain.
11. It is easy to breathe when snorkeling with only your face beneath the surface of the water, but quite difficult to breathe when you are submerged nearly a meter, and nearly impossible when you are more than a meter deep (even if your snorkel tube reaches to the surface). Figure out why, and explain carefully.

12. Why is it that when cars pass each other at high speeds on the road, they tend to be "drawn" to each other?
13. Why does the fire in a fireplace bum more briskly on a windy day?
14. In a department store, an airstreams from a hose connected to the exhaust of a vacuum cleaner blows upward at an angle and supports a beach ball in midair. Does the air blow under or over the ball to provide support?
15. The diameter of a fire hose varies with the flow rate of water inside. The hose may be relatively narrow, and at another time puffed up like a fat snake. In which case is water flowing fast, and when is water hardly flowing at all?
16. You overhear a conversation between two physics types. One says that birds couldn't fly before the time of Bernoulli. The other says, not so. That birds could fly before the time of Bernoulli, but couldn't fly before the time of Newton. Humor aside, what points are they making?

Appendix G:

UCHRIS Letter of Approval

MICHIGAN STATE
University

November 17, 2000

TO: Merle HEIDEMANN
118 North Kedzie Hall

RE: **IRB# 00-494** CATEGORY:1-A.B.C
APPROVAL DATE: November 16,2000

TITLE: DEVELOPMENT AND ASSESSMENT OF INQUIRY BASED LEARNING OF PHYSICS THROUGH LABORATORY INVESTIGATIONS

The University Committee on Research Involving Human Subjects' (UCRIHS) review of this project is complete and I am pleased to advise that the rights and welfare of the human subjects appear to be adequately protected and methods to obtain informed consent are appropriate. Therefore, the UCRIHS approved this project.

RENEWALS: UCRIHS approval is valid for one calendar year, beginning with the approval date shown above. Projects continuing beyond one year must be renewed with the green renewal form. A maximum of four such expedited renewals possible. Investigators wishing to continue a project beyond that time need to submit it again for a complete review.
REVISIONS: UCRIHS must review any changes in procedures involving human subjects, prior to initiation of the change. If this is done at the time of renewal, please use the green renewal form. To revise an approved protocol at any other time during the year, send your written request to the UCRIHS Chair, requesting revised approval and referencing the project's IRB# and title. Include in your request a description of the change and any revised instruments, consent forms or advertisements that are applicable.
PROBLEMS/CHANGES: Should either of the following arise during the course of the work, notify UCRIHS promptly: 1) problems (unexpected side effects, complaints, etc.) involving human subjects or 2) changes in the research environment or new information indicating greater risk to the human subjects than existed when the protocol was previously reviewed and approved.

If we can be of further assistance, please contact us at 517 355-2180 or via email UCRIHS@msu.edu. Please note that all UCRIHS forms are located on the web: http :/ /www .msu .eduluserlucrihs

Sincerely,

Ashir Kumar, MD Interim Chair, UCRIHS

AK: bd
cc: Russell Billings
3303 N. Irish Rd. Davison, MI 48423-9501

Appendix H:

Parent and Student Consent

Kearsley High School
Russell L. Billings
4302 Underhill Drive
Flint, MI 48536
(810) 591-9807

Dear Parent(s) & Student,

I am currently involved in an educational research project entitled: Development and Assessment of Inquiry Based Learning of Physics through Laboratory Investigations

Explanation of Research:

The goal of this project is to assess effective learning of scientific concepts; skills and how they pertain to learning primarily through inquiry based investigations. Students are to be introduced to new concepts primarily through hands on activities.

I will be beginning research in the second week of the first quarter and plan on carrying it through until the end of the first semester in January. All students will essentially be doing the same activities with the difference being that the students who consent to participate in this study will have their results anonymously analyzed to asses the effectiveness for this mode of science training and instruction.

Participation is strictly voluntary based upon the consent of the subject and his or her legal guardians. Subjects may refuse to participate in certain assessments as they pertain to the research and may chose to discontinue the study at any time without penalty. All data gathered from the subjects will be treated with strict confidence. The subject's privacy will be protected to the maximum extent allowable by law.

Any questions or concerns that you may have by participating in this study can be answered by: Russell Billings (810 – 591-9807), teacher conducting the study, Merle Heidemann (517-337-9410) Michigan State University Division of Science & Mathematics, David E. Wright (517) 355-2180, Michigan State University Committee on Research Involving Human Subjects, chair.

You indicate your voluntary agreement to participate by completing and returning this questionnaire.

Student Subject Name: ______________________________ Date______

Student Subject Assent: ______________________________ (Signature)

Parental or Legal Guardian Consent: ________________________(Signature)

Parental or Legal Guardian Consent: ____________________ __________
(Printed Name) Date

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