ASSESSING THE EFFECTIVENESS OF THE HBL PEDAGOGY

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DEDICATION

This thesis would probably never have happened without significant contributions and encouragement from my parents, Wallace and Margaret Hasty, and my wife, Genny Hasty. This dissertation is dedicated to them.

I enjoy the privilege of having two exceptional parents. All my life, they have provided support, affection, guidance, and encouragement. Any words I could use here would be inadequate to express my gratitude and appreciation for their efforts and sacrifices on my behalf. Ultimately, I am left with two simple but heartfelt phrases:

Thank you,

and

I love you.

I believe you both know how much I mean by them.

As a child, my father would constantly admonish me to better myself through education. His formal education ended after the ninth grade; he obtained a GED after enlisting in the U.S. Army. However, he has always seemed to feel that others having extensive education were somehow 'smarter' and had intellectual advantages unavailable to him. After completing this latest and most important chapter of my education, I would like to remind him:

A person does not need extensive education to have intelligence.

Genny, my wife of six years, has labored above and beyond the call of duty while I pursued this degree. She has been a source of support and encouragement

throughout, despite my general irritability and contentions that “I want my life back!” as I wrote this thesis. Now that my (ahem) ‘fecis’ is done, I look forward to spending many wonderful years with you, looking back on this. Thank you for everything!

Honey, put on your travellin’ shoes - let’s go to Italy!

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PREFACE

"I love teaching...Initially I thought - as many people do - that what is taught is learned, but over time I realized that nothing could be further from the truth." - Eric Mazur[1]

After graduating in 1993 with a Master of Science degree in Physics, I accepted a teaching position at a four-year institution. I had enjoyed teaching labs and recitations in graduate school, and I looked forward to the challenges and rewards of sharing physics with my future students. Over the course of a year, I developed lectures, carefully considered demonstrations, and did my 'level best' to create an optimal learning situation. I reflected at length on those educational tools that had made an impact on me as a student and carefully worked them into my teaching. Those things I viewed as less than helpful were discarded and I guarded against their use in my classes. Although I may not have been the most effective public speaker, self-evaluation of my lectures reassured me that I was doing an (at least) adequate job of presenting the material, solving problems, and answering questions. Fellow faculty who listened in on my classes assured me I was doing well. I was well liked by the students.

There was only one small problem: my lectures did not seem to work.

Despite my best efforts, repeated revisions, and implementation of reasonable advice from fellow faculty and friends, my students were not learning the material as desired. They would work problems, ask questions, and still flounder when confronting new problems or situations. Everything I had considered so effective for me as a student seemed to make only marginal impact on my students. After one year, I was nearly at my wits' end.

During the fall of 1995, I returned to my alma mater and happened upon Dr. Bruce Ackerson in a stairwell. I had taken a course from him in graduate school and respected his knowledge and teaching abilities. During our conversation, I discussed my 'troubles' and dissatisfactions (quite at length, I am sure) and sought advice. Dr. Ackerson mentioned that there was a relatively recent body of literature devoted to addressing similar experiences. Although I recall few other particulars regarding our visit, I count that conversation as the first crucial turning point in my career as an educator.

Eventually, I returned to Oklahoma State University to pursue a doctorate in Physics. In the long (and uphill) journey towards my PhD, I have been fortunate in at least three other ways: my collaboration with Dr. Ackerson has continued, I was exposed for the first time to the Socratic inquiry of Lillian C. McDermott's Physics by Inquiry (PBI), and I worked as a Hypothesis-Based Learning (HBL) development team member on a recent Star Schools grant from the U.S. Department of Education. Each of these has had its influence on my instructional abilities; without any of these, I would stand much less chance of experiencing the instructional success I desire.

My first academic appointment was an eye-opening experience. Looking back, it is possible I was overly naïve. I knew no one in Physics that had taken even a single Education course. In fact, the entire idea of scientists learning to teach from the professionals in the college of Education seemed to be held in mild contempt. After all, who could argue that a successful science faculty member having a rich research career, excellent academic credentials, and several years' experience teaching could not effectively instruct students in his own discipline? Physics students are nothing like education students, nor is the curricular material similar; apparently, no reason for collaboration existed. Furthermore, it seemed apparent that most established Physics faculty perceived the entire literature and research in Physics Education to be a waste of time; something trivial, something beneath the dignity of a 'real' scientist.

This body of literature and research, Physics Education Research (PER), is causing the discipline to closely consider our unexamined assumptions regarding students, our teaching, and our discipline. How fortunate we are to live in this time, when we can witness the development and implementation of ideas allowing us to more effectively share our discipline with students. Physics holds that the universe is an understandable place. Humans, as inhabitants of this place, should be at least somewhat understandable. Having been more understood, students stand to gain in understanding this marvelous body of knowledge we term 'science'.

According to Plato, Socrates declared in Apology 38a: "The unexamined life is not worth living." Based upon my limited experience, I would postulate a (less beautiful, but more useful) corollary: "Unexamined instruction is not worth using." What scientist, upon confirmation that his model is incapable of accounting for a system's observed behavior, would continue his investigations without first revising his model?

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CHAPTER 1

INTRODUCTION

1.1 Introduction

"As physicists, we know that maximum power is delivered from a source to a load only if their impedances are matched by a transformer. The physics instructor is a vast source of factual, conceptual, and procedural knowledge about physics, but this source is totally mismatched to the student 'load.' If the impedances are mismatched, knowledge is either transmitted (well characterized by 'In one ear, out the other') or reflected (regurgitating what the professor wants to hear, then forgetting it immediately after the exam), but little is absorbed. To achieve the desired student outcomes, we must use the correct educational transformer - that is, teaching materials and methods that are properly matched to an accurate assessment of the knowledge state of the students." - R. Knight[1]

Education in the United States is undergoing a transformation due to ongoing assessment of instructional strategies and the students receiving instruction. These changes are occurring across most science disciplines and mathematics. These changes are driven by an ever-increasing body of research indicating that traditional instruction, while enjoying a set of advantages, has a number of liabilities. If we educators are to effectively interact with our students and allow them a more effective perception of the world, we must know our students and also know how to avoid the more damaging or less effective instructional pitfalls. The only way for this to proceed in a rational fashion is for us to study our students and interactions and then to apply what we learn.

Primary and secondary education has been extensively studied. To address difficulties in student learning and increase educational effectiveness, the National Science Education Standards (NSES) specify that 'inquiry' will be an integral component of the curriculum and utilized for all audiences, kindergarten through twelfth grades. The definition of inquiry is left somewhat open in the NSES, but the clear expectation is that all students learn best through a series of activities that allow connections between real-world object manipulation and the conceptual structures underlying our modern understanding of the phenomena.[1]

University instruction is also changing, albeit more slowly, in response to this literature. Chickering and Gamson[2] indicate that undergraduate instruction benefits from the following seven 'good practices':

1. Encourage contacts between students and faculty.

2. Develop reciprocity and cooperation among students.

3. Use active learning techniques.

4. Give prompt feedback.

5. Emphasize time on task.

6. Communicate high expectations.

7. Respect diverse talents and ways of learning.

Note the emphasis on communication and involvement of the student, while the role of instructional staff is more managerial than oratory in style. Of several 'active learning techniques', grouping University students into teams has spawned a large literature. This 'cooperative learning' strategy has indicated several lessons important in the context of this dissertation, several of which will be discussed further in the literature review.

Traditional instruction, in secondary and University education, is instructor-centered: interactions hinge upon transmission of information from the instructor to the student in a didactic, serial manner. Students are modeled as sponges, able to 'soak up' the instructor's expertise by being passively attentive.[3]

1.2 Lecturing and Traditional Physics Instruction

> *"[Lecturing] is a very efficient method to transmit information in terms of the time interval needed. We know the concepts and techniques, and students do not. Why not just tell them? Study after study indicates that this expository method is very ineffective - the transmission is efficient but the reception is almost negligible."* - A. VanHeuvelen[4]

In the seventh grade, American students usually encounter traditional education in its native form: a teacher, whom one takes on faith understands the material being presented, transmits 'knowledge' to the student through the agency of telling. That is, teachers typically present information to the student in the form of a lecture.

The act of lecturing has several presuppositions, including the implicit assumption that the student has sufficient linguistic skill to understand the words used. The student must be capable of remaining attentive and in a receptive mental state for the lecture duration. The student must be able to listen effectively while organizing (or reorganizing) his mental constructions regarding the lecture material. He must maintain his attention while in the act of recording information presented in the lecture. The presented information must be remembered by the student, which (hopefully) does not conflict with other stored information or interests. The student is expected, on quite short timescales, to assimilate information and be prepared to ask clarifying questions of the lecturer when he has difficulty. Sufficient 'telling' on the lecturer's part will impart the lecturer's understanding to the student. Finally, the absence of questions is taken as a tacit contract that the student understands the material and can use it effectively and appropriately.

These underlying assumptions contribute directly to a few lecturing 'trouble spots' identified by Knight[4]:

1. The attention span of the audience is (at best) 10 to 15 minutes,
2. Information is presented too quickly for assimilation or reflection,
3. Lecture information is simply a 'rehash' of textbook material,
4. Lectures focus on material at a remove from actual phenomena, like derivations or demonstrations,
5. Most students have no experience with or training in effectively listening to lectures,
6. Students frequently do not know how to record pertinent lecture information.

Given these potential impediments to learning, why do we lecture? This author postulates that we educators lecture simply because it is the easiest and most time-efficient activity we can perform. Telling, which puts the intellectual burden on the listener, has always been easier than asking, which places much of the responsibility for true communication on the 'asker'. Other points aside, what educator physically has the time necessary to attend each student individually, discern where the student has problems, and tailor a suitable interaction yielding a desired outcome? Given the low financial remuneration, long working hours, large class sizes, additional time obligations having nothing to do with 'teaching', and the overwhelming burden of grading, lecturing may be the only sane option for teachers. Is it really realistic to suppose that the average American teacher can interact meaningfully with many students over the course of seven hours (not counting time spent grading)?

The real problem with lecturing, however, is that an enormous body of research has demonstrated that lecture-format instruction is ineffective as an educational pedagogy for the majority of students.[5–12] Students must be personally and mentally involved to learn effectively.[4] This research suggests a shift in instructional style towards learner-centered interactions, where the students are called upon to be active in the construction and extension of their knowledge and where the instructors are more like 'tour guides' than 'infallible fountains of knowledge'.[5,13,14]

> *"This is not to say that lectures are never effective. The lecture mode appears to work best where instructor and students share a common set of beliefs and assumptions, such as in graduate classes. Even in the introductory class, short periods of instructor-centered discourse can clarify difficult issues or provide background information. But extended lectures, particularly formal lectures of deriving results, appear to be the least effective mode of instruction."* - R. Knight[4]

In the sciences, lecturing does not provide the student with sufficient conceptual understanding or the problem solving ability he will be judged upon. The typical student, after exposure to semesters or years of instruction, has no understanding of what constitutes science. Students who succeed in the lecture arena are typically good at memorization and written 'regurgitation', not at utilizing the material in a new or unusual manner.

The systemic difficulties may extend deeper than lecturing: rather than accept at least partial responsibility for these shortcomings, responsible staff are frequently willing to lay the full blame for poor performance on the student's shoulders. Educational reform has historically been seen by scientists to be a series of vogues that end with results inferior to lecturing. Entrenched staff see no reason to change, for they themselves are products of an 'effective' system; those who cannot perform are seen as not worthy of a passing grade, a diploma, or reform. Change, especially when much needed, is difficult for all concerned.

1.3 Physics Education Research

> *"People must build their own mental models…You cannot teach anybody anything. All you can do as a teacher is make it easier for your students to learn…It (constructivism) asks us to focus less on what we are teaching, and more on what our students are learning."* - E.F. Redish[15]

> *"All individuals must construct their own concepts, and the knowledge they already have (or think they have) significantly affects what they can learn. The student is viewed not as a passive recipient of knowledge but rather as an active participant in its creation. Meaningful learning, which connotes the ability to interpret and use knowledge in situations not identical to those in which it was initially acquired, requires deep mental engagement by the learner."* - L. C. McDermott[15]

Fortunately, the past two decades have seen an increasingly well-supported body of literature illuminating some of the pitfalls and triumphs of educational practice.[15] Limited reforms and scientists interested in pursuing this body of literature have been increasingly accepted into their respective communities. The establishment and extension of this literature makes it increasingly difficult to deny the existence of educational problems. Scientists who are now forced to enter this arena can only aid in solving its problems, as they bring skills and perceptions outside the discipline of education. Interestingly, most of the resistance to educational reform in the sciences comes from practitioners who have had very little, if any, formal training in effective teaching. This does not downplay the abilities of those individuals, but rather exposes their prejudices against personal and systemic change. Professionals in education who recognize that a problem exists in instruction are ethically obligated to consider and pursue its solutions. The problems in education are not singular, not limited to any particular discipline, very complex, and likely beyond the ability of any single methodology or discipline to remedy.

Physics education research is the study of how students learn physics. It uses psychology, physics, education, and cognitive research to gain insight into how students understand, classify, use and change their knowledge of the physical world and its organizing physical principles. It is mostly concerned with understanding the conceptual framework held by students and in investigating how students solve problems using that framework. PER has demonstrated[4]:

- Students have preconceptions regarding the physical world,
- These preconceptions are at odds to those held by physicists,
- Students use their preconceptions to solve problems rather than material presented in courses,
- Student preconceptions are exceptionally resistant to modification or change, despite instruction,
- Student knowledge is organized mostly according to superficial 'problem type' rather than by underlying principles,
- Students do not usually develop a 'principled' or functional understanding of physical phenomena, and
- Students cannot address previously unseen situations effectively.

PER is concerned with discovering the most common modes of student thinking with intent to maximize student benefit by altering instructional methods. However, this research is not so much concerned with providing educators with an optimal teaching ‘formula’ as in indicating which approaches are most likely to be fruitful and which should be avoided.[4]

1.4 Statement of the Problem

It has been well demonstrated that lecturing, as a form of education, has many disadvantages. These disadvantages may be particularly severe for those individuals interested in elementary education. This audience responds differently to instruction than science and engineering students, necessitating a change in the instruction given to them. One method to address this relative inaccessibility of science is to provide students inquiry-based instruction. This instruction provides material to the student at a slower pace, allows for more opportunity to resolve questions about the material, and typically involves group efforts. Each of these has been shown to be important to those individuals interested in becoming teachers, especially at the elementary level.

Many inquiry-based instructional pedagogies exist. These range the full spectrum of inquiry, from directed to open. HBL, an exceptionally open form of inquiry instruction, is a recent addition to the spectrum of available inquiry pedagogies. No studies exist comparing HBL to any other pedagogy. The primary purpose of this dissertation is to provide a comparison between HBL and a different inquiry pedagogy in an attempt to probe the strengths and possible weaknesses of HBL. PBI, a highly directed inquiry pedagogy, was chosen as the baseline pedagogy for two reasons. The author has had extensive experience with PBI and trusts its effectiveness, and PBI is represented in the literature as an effective instructional pedagogy for the elementary education audience.

Given these quite different inquiry strategies, many questions could be asked. Assuming an elementary education audience, the three questions of most interest within this dissertation are:

1. What are the relative strengths and weaknesses of HBL compared to PBI?

2. Which type of inquiry instruction (open or directed) is most appropriate for this major?

3. What student differences are caused by different inquiry pedagogies?

The answers to the latter two questions obtained by the studies presented in this dissertation will form the basis of the answer to the first question.

1.5 Overview of the Research Design

All aspects of the studies presented in this dissertation have been approved by a successful IRB application from Oklahoma State University, presented in Appendix A.

The studies presented in this dissertation proceed from the choice of two very different inquiry pedagogies: Physics by Inquiry (very directed) and Hypothesis-Based Learning (very open). The following 'pre/post' series of study designs was created to answer specific aspects of the questions posed in the problem statement, as detailed in the research questions section.

Undergraduate elementary education students at Oklahoma State University who enrolled in Physics 1313 during the fall 2003 and spring 2004 semesters were instructed using either Physics by Inquiry[16,17] or Hypothesis-Based Learning for an entire semester. The two course sections covered identical course content. Data was taken throughout the semester to compare group performances.

The total student population of 83 included 4 students from majors other than elementary education. All students were assessed using the instruments detailed below.

1.5.1 Prior to instruction

Before receiving instruction of any kind, students completed two instruments on the first class day. This information was used to establish baselines for future outcome comparisons. Student self-efficacy was assessed using the STEBI-B instrument[18]. Physics expectations were assessed using the Maryland Physics Expectations Survey (MPEX)[19].

1.5.2 During instruction

As a measure of physics content mastery, four physics content-specific questions were collected from Midterm and Final exams. The two problems from the Midterm exam covered related physics content, while the two Final exam problems involved material different in content from one another and from the Midterm.

1.5.3 After instruction

After receiving all class instruction, all students were assessed using three instruments on the final class day. Student self-efficacy was assessed using the STEBI-A[20]. The MPEX was used again to assess physics expectations. The Science Process Assessment for Middle School Students[21], was used to assess student mastery of science process skills.

Further details of the study methodology are discussed in Chapter 4.

1.6 Research Questions

Undergraduate elementary education students were treated as detailed above in the research design overview. The assessments attempted to address the following four research questions.

1.6.1 Research Question 1:

How will the self-efficacy of elementary education students be changed by one semester of open or directed inquiry instruction?

1.6.2 Research Question 2:

What are the influences of one semester of open or directed inquiry instruction on elementary education students' physics expectations?

1.6.3 Research Question 3:

Are there differences in elementary education students' physics process skills resulting from one semester of open or directed inquiry instruction?

1.6.4 Research Question 4:

Does exposure to one semester of open or directed inquiry instruction cause differences in elementary education students' physics content knowledge?

1.7 Assumptions

Given these initial conditions, assumptions were made regarding the students and instructional staff.

1.7.1 Assumptions Regarding Students

Students in this collection of studies were assumed to have enrolled in either course section randomly. The student populations of either group were likewise assumed to initially be homogenous, identical, and representative of the typical elementary education student population. Students, once in a course section, were assumed not to collaborate with friends or students from the other course section, or with former students. No students changed course sections during these studies.

1.7.2 Assumptions Regarding Instructional Staff

Instructional staff were assumed to be proficient in both pedagogies (PBI and HBL) and unbiased in their administration, interpretation, collection, and evaluation of student data. Staff were also assumed to be able to clearly differentiate between course pedagogies and use them independently, limiting any crossover effects from one class to the other.

1.7.3 Assumptions Regarding the Physics 1313 Course

All changes in student performance are assumed to come about solely due to the influence of the course section chosen by the student. No information regarding pedagogy was available to students prior to the first class day. The time of each course section was assumed to have no influence upon study outcomes: instruction occurred during three two-hour classes per week, beginning at either 9:30 am or 1:30 pm.

1.7.4 Assumptions Regarding Instruments

Students completing the instruments used are assumed to adequately understand questions posed by the instrument and to have answered to the best of their ability. Collaboration between students was assumed not to be present, as the instruments were all administered under controlled circumstances that did not allow collaboration. Instruments used are assumed to be valid and adequately supported by the literature base. This assumption has been met for each of the three published instruments used (STEBI, MPEX, and SPAMSS). However, no studies of reliability or validity have been conducted for the Exam Item questions. Exam Item questions are adequate to provide a straightforward comparison between the populations and are not intended to be extended outside these studies. Results drawn from the instruments are assumed to be obtained without influences from evaluatory staff.

1.8 Methodological Issues and Limitations of the Study

The studies conducted in this dissertation are exploratory. They represent first efforts at obtaining experimentally-derived evidence for the effects of HBL on elementary education students. Further study will doubtless be needed for an adequate evaluation of HBL, as these studies are not intended to be exhaustive.

Conclusions drawn from instruments derive their strength and applicability from the literature base supporting them, as well as the validation and reliability studies conducted by their designers. Assuming the instruments to have adequate support, conclusions from these studies may be validly extended to populations outside the study population. This is subject to the relatively small sample-size limitations of the studies. However, these sample sizes are sufficient to infer statistical significance[22] and therefore may be extended to other elementary education populations.

1.9 Significance of the Study

The studies conducted in this dissertation serve two major purposes. First, they establish initial data upon the effectiveness of HBL. As of this writing, other data serving this purpose does not exist. No data, comparisons, or analyses regarding the effectiveness of HBL have been published in any peer-reviewed forum. This information will prove helpful in the further development of HBL and its dissemination into programs and schools across the nation. This data will inform future studies of HBL and may also serve as a guide for comparing other instructional inquiry pedagogies.

Secondly, these studies provide a direct comparison of the advantages in using an exceptionally open inquiry pedagogy relative to one that is highly directed. Support for directed inquiry in physics may be found in the literature relatively easily; however, few sources exist providing information regarding the effects and outcomes of using an open inquiry pedagogy. Favorable comparisons between open and directed inquiry may have far-reaching implications for the use of either pedagogy to provide physics instruction to elementary education students.

CHAPTER 2

PEDAGOGY DISCUSSION AND CONTRAST

2.1 PBI Review and Discussion

2.1.1 Historical Background

Under the direction of Dr. Smith Holt, Director of the Center for Science Literacy and former Dean of the College of Arts and Sciences, four science courses were created and offered for the curriculum of Elementary Education majors at Oklahoma State University in 1998. These four science courses, from the disciplines of physics, chemistry, earth science and biology, were created, taught, and administered by science departments rather than the College of Education.

It was desired that each of these courses specifically address the needs of future teachers in two ways. First, as these students traditionally were not required to take more than 3 hours of science at university (although this was later increased to 12 hours), these courses were to bolster student understanding of and appreciation for science. In short, these courses were to give students an understanding that science is not 'just a collection of facts' for them to memorize, but rather a process by which new information is gained. Given this understanding, the courses were to illustrate that the process of science was accessible to scientists and nonscientists alike: teachers, prospective teachers, and students could profitably pursue this process and gain new knowledge. Secondly, these four courses were specifically created as 'inquiry-based', 3 credit-hour laboratory courses with little or no lecture component. This criterion was used since both experience and the literature suggested that:

1. inquiry, ‘hands-on’, or ‘brains-on’ learning was to form a core component of the standards used for teachers in public schools across the nation,

2. lectures do not create understanding as well as interactive methods that actively engage students,

3. teachers tend to teach their own students in the manner they are taught, and

4. teachers comfortable with science were more likely to cultivate and support that interest in their students.

Given that no inquiry-based laboratory physics courses were taught within the OSU physics department, Dr. Bruce Ackerson led an investigation into various instructional alternatives that would simultaneously meet the needs of the courses and develop rigorously correct physical knowledge. After much review, it was determined that **Physics by Inquiry**, developed by Lillian C. McDermott and the Physics Education Group (PEG) at the University of Washington in Seattle[16,17], represented the best overall solution to both criteria for a physics course. To familiarize himself with the instructional method, Dr. Bruce Ackerson attended a summer 1998 PBI training workshop conducted by Dr. McDermott and the PEG in Seattle. The author received his PBI training from Dr. Ackerson during the fall 1998 semester.

This dissertation is primarily concerned with Physics 1313, the physics course created in 1998 to fulfill the needs of elementary education majors. The course description from the OSU course catalog reveals the intent and scope of the course[23]:

> “PHYS 1313 (L, N) Inquiry-based Physics. Lab 3. Properties of matter, motion, light and color, electrical circuits and energy conservation. Recommended for elementary education majors as a model course to learn and teach science.”

2.1.2 Historical Development of Physics 1313 at OSU

Physics 1313 was taught at OSU from 1998 through the 2002 spring semester using Physics by Inquiry exclusively. PBI was used in half the course sections each semester from the fall 2002 semester through the spring of 2004. During the last two years of this interval, curricular material from PBI was adapted to the HBL pedagogy. The first of these years involved creation of HBL material and laboratory activities, while the second year was used to gather data from each of the differing pedagogies for the studies conducted in this dissertation. Physics 1313 continues to be taught at OSU as of this writing, and has used HBL as its sole instructional pedagogy since the fall 2004 semester.

Given the central role of PBI in the development of Physics 1313 and its use in these studies, a further discussion of PBI is warranted.

2.2 Physics by Inquiry (PBI)

PBI is a laboratory-based instructional pedagogy specifically concerned with physical science content. Physics content and scientific investigation forms the unifying theme throughout the two volumes of **Physics by Inquiry**. The following quote adequately summarizes the intent guiding the development of PBI[16]:

> *"Physics by Inquiry is not meant to be passively read. The modules do not provide all the information and reasoning included in a conventional text. There are gaps that must be bridged by the student. The process of science cannot be learned by reading, listening, memorizing, or problem-solving. Effective learning requires mental engagement."*

Major PBI pedagogical features are presented below in a brief outline.

2.2.1 PBI Features

Students experiencing PBI follow a highly scripted set of laboratory instructions that completely replace traditional lectures. PBI is self contained, presenting all required information to students as it is needed. Physics content is presented in a series of conceptually related modules that utilize 'real-world' rudimentary equipment. Within a module, students read background information, definitions, and encounter examples of commonly used experimental or analysis techniques. They are also presented opportunities to investigate new situations.

The PBI module structure leads students towards conceptual or factual knowledge in discrete steps. The most common mode of guiding student investigations proceeds along the cyclic model, punctuated with 'challenge questions' and novel viewpoints or situations:

- observe/measure
- predict outcomes/address pointed question(s)
- further investigation
- generalize
- discuss

This cyclic model may be briefly summarized as follows. First, students are presented with a new physical or conceptual situation and asked to make specific observations or measurements. Second, students consider outcomes under changed circumstances or answer 'pointed' conceptual questions relevant to the phenomenon. Third, the situation is extended in some way and students are asked to collect additional information about the system or its internal relationships. Fourth, students are instructed to address pointed statements regarding the system's underlying physical concepts, or to generalize system behavior into a more formal 'rule'. These rules are recorded and usually tested immediately or addressed in upcoming module sections. At the completion of a major section of material students are explicitly instructed to "check your ideas with a staff member". These 'checkpoints' are addressed below in the 'Student-Instructor Interactions' section. At any time in this cycle, pointed conceptual questions, novel hypothetical student viewpoints, or specific lines of investigation may be introduced to the student. Any of these supplemental activities are used to address common misconceptions, conceptual confusion, or reinforce immediately preceding material.

Notebooking is a central issue in PBI. Students are continually reminded to develop models, record information, summarize investigations, or address questions in notebooks as an integral portion of the pedagogy. These reminders to perform notebooking activities occur after every activity students perform, without exception. Notebooks may be used on exams or as a resource whenever needed. Students are explicitly instructed to record particular kinds of information (summaries, data, predictions of system behavior, reasons underlying predictions, patterns, question answers, etc) in their notebooks. These notebooking activities develop writing skills, encourage appropriate content usage, support the development of logical arguments and structures, and train students in acceptable data presentation methods. These writing activities are intended to spark metacognitive activities in students, causing them to reflect on the use and development of their knowledge.

It is interesting to note that upon scanning through the PBI text, non-PBI faculty feel that the curriculum should go very quickly, that it is 'too easy' or not rigorous, that it covers too little material, that it is not 'university-level' instruction, etc. This perception is totally inaccurate. The author typically describes PBI to interested parties thus: Going through the material as a student is a completely different experience than simply reading it. The only fair way to evaluate PBI is to force oneself to complete it as rigorously as one's own students.

2.2.2 PBI Student-Student Interactions

> *"Through an in-depth study of simple physical systems and their interactions, students gain direct experience with the process of science. Starting from their own observations, students develop basic physical concepts, use and interpret different forms of scientific representations, and construct explanatory models with predictive capability. All the modules have been explicitly designed to develop scientific reasoning skills and to provide practice in relating scientific concepts, representations, and models to real world phenomena."*[16]

Students in PBI are grouped into small groups, typically comprised of 2 to 6 members. Individual students work largely at their own pace through the material presented in the text, but are seen to be a collaborative group. Students are encouraged to work together on investigations, helping one another with intellectual and equipment challenges. This 'individuals in teams' approach fosters several advantages, not the least of which is an introduction to meaningful collaborative teamwork. Individual leadership is one of the first-seen results of group interactions.

2.2.3 PBI Student-Instructor Interactions

> *"Physics by Inquiry has been designed for courses in which the primary emphasis is on discovering rather than on memorizing and in which teaching is by questioning rather than by telling. Such a course allows time for open-ended investigations, dialogues between the instructor and individual students, and small group discussions."*[16]

Instructor - student interactions in PBI are entirely Socratic; that is, students are guided through the curricular material with appropriate questions designed to cause the student to address his difficulties. This style of interaction is immensely difficult, and is impossible to acquire quickly. When done with skill and finesse, this instructional strategy is quite effective.

As students progress through the PBI curriculum, they encounter regularly-spaced checkpoints. These checkpoints are Socratic in nature and serve a variety of purposes. First, they allow students to demonstrate understanding of the relevant data and physical concepts. Second, they allow staff to verify that students are making relevant measurements and inferring conclusions using appropriate logic. Third, they allow staff an opportunity to insure that current student models are consistent with previous knowledge. This is crucial, as students frequently cannot discern (or lose sight of) the larger context of their investigations and are happy to form piecewise models of limited applicability. Checkpoints also allow staff to insure that all students are participating meaningfully in the inquiry, since it frequently happens that a fraction of group members are content to sit back and let the stronger group members lead the investigation. Each of these purposes is well served through the student - instructor interactions, and it is only through them that the students remain motivated, focused, and have models grounded in experimentally-verified reality.

The choice of Socratic instructor - student interactions has far-reaching implications for the course. One of them is that students are usually unprepared to be questioned about their deductions, as they normally receive questions from traditional staff only when they attempt to support an 'incorrect' position. Another is that these questions force students to perform the process of logical deduction themselves, which is another unfamiliar situation for them. These questions assume that the student has performed at least some of the mental work ahead of time and that they can, upon reflection, deduce where their difficulties lie and address them in light of the question type and content. Finally, the instructor is demoted from 'informational source' to 'tour guide' (and 'evidence/fairness enforcer') as the student proceeds through the curriculum. As a result, students perceive that they are able to understand at least some aspects of the world on their own. Hopefully students also adopt a more evidence-based perspective when confronted with an unfamiliar situation, rather than seeking an appeal to information authorities.

2.2.4 PBI Adoption/Use Issues

> *"Physics by Inquiry is particularly appropriate for preparing preservice and inservice K-12 teachers to teach science as a process of inquiry. The modules can also be used to help underprepared students succeed in the mainstream science courses that are the gateway to majors in science, mathematics, engineering, and technology. For these student populations, as well as for those in the liberal arts, the curriculum helps establish a sound foundation for the building of scientific literacy."*[16]

Adapting PBI for use in an institution's existing courses is moderately difficult, as the curriculum is self-contained and is difficult to use piecewise. Rather, PBI is usually used to replace existing traditional coursework (or at least the laboratory component). Upon deciding to transition towards PBI, institutions and instructional staff must allow sufficient time and support for staff to be properly trained. Adequate training of instructional staff is likely the single largest factor in the success of the PBI pedagogy, and should not be overlooked. The transition from a 'teaching by telling' instructional method to the guided Socratic inquiry of PBI is potentially difficult. Instructional staff must be confident in their ability to foster and maintain Socratic student interactions. Staff must also have enough confidence in the curriculum to allow students to proceed without necessarily coming to resolution on important issues. Finally, pressure from students on the staff to revert to the didactic instructional method is a nontrivial issue. Students have been trained since primary school to desire the lectures and activities of a traditional classroom, and have significant difficulties in making the transition away from them. However, after some initial period of discomfort many students come to desire the freedoms and challenges of these Socratic interactions.

PBI uses relatively ‘low tech’ equipment in experiments: test tubes, wooden balances, batteries, bulbs, hot plates, beakers, construction paper, acetates, prisms, paint, and similarly uncomplicated equipment. Electronic equipment, such as electronic scales or multi-meters, is used infrequently. Much of the necessary equipment may available from traditional laboratory supplies, though it is likely that significant equipment expenses would still be incurred by institutions adopting PBI due to the amount of equipment serving a single specialized purpose. However, most of the equipment used in PBI labs may be used in more than one module or experiment. On the whole, PBI equipment is both less expensive and easier to maintain than traditional laboratory equipment.

Additional concerns regarding PBI use arise from the student-instructor interactions: the frequency and duration of these interactions necessitates a student/teacher ratio of approximately 10:1. Student/teacher ratios exceeding 15:1 typically become unmanageable - students either proceed beyond checkpoints until a staff member can meet with them, or they are forced to stop pursuing new material until a staff member addresses the checkpoint. At this point, additional properly-trained staff is necessary to facilitate smooth student progress through the curriculum.

Each of these PBI pedagogy features require significant alterations from the traditional instruction model, and these changes are difficult for the students and instructional staff. Despite the potential intellectual payoff, changes are difficult to accept for educators outside PBI as illustrated by the following anecdote. The author presented his experiences with PBI to a group of university educators at the University of Central Oklahoma in Edmond. After illustrating various features of the pedagogy and giving several examples regarding the use of evidence to support conclusions, a real student interaction was discussed. The student discussed had a geocentric solar system model capable of describing the observed motions of objects across the sky, despite seeing other models many times on television and in school settings. Interactions with the student were described, as were her evidence and conclusions. One of her conclusions was that the geocentric model worked adequately. One of the audience members, clearly incredulous, asked if the student had been instructed that the solar system was not adequately described by a geocentric model. He was obviously upset with the author's reply that, since the student's model was capable of handling the observed phenomena, her model was allowed to stand uncorrected. The audience member could not believe that the student's needs were served by letting her understanding remain incorrect. He became incensed when asked for evidence (gathered with equipment available to the student) sufficient to necessitate correction of the student model, ultimately walking out of the presentation (not, however, before it became apparent that he had no sufficiently 'good' evidence). The audience member had missed the two central points of the entire presentation. First, student models are based upon their evidence and must be able to adequately describe currently observed phenomena. This is the true nature of science: available data drives current models, which are subject to revision. Second, despite the student's 'incorrect' model and without compelling reasons to change it, the student had a model adequate to her data. Causing her to change models without appropriate evidence would have been impossible without telling her that the model was incorrect - an action outside Socratic instruction. Clearly 'teaching by telling' is the easiest form of instruction, but not always the method best suited to student needs. Equally clear is that not all instructors desire, like, or value situations not involving 'telling'. However, one huge problem looms for such persons: what happens when the information 'told' is incorrect?

2.3 The Transition of Physics 1313 Towards HBL

The Center for Science Literacy was the recipient of a five year Star Schools grant from the U.S. Department of Education in 2000. This grant ultimately involved the development and implementation of HBL in public schools across the nation. The author was fortunate to work as a development team member on this project. In the early years of the Star Schools project, the author conducted summer workshops for inservice public school teachers as part of an unrelated project. It was during this time that he first became acquainted with HBL through discussions with Dr. Mark Rockley and attendance at Dr. Rockley's HBL summer workshop.

After seeing HBL used in classroom situations, and through his involvement with the Star Schools grant, the author decided to use HBL in Physics 1313. HBL course material paralleling that of PBI was developed and tested from the summer of 2002 through the summer of 2003. Upon completion and use of this material in classes, it was decided to compare the effects of PBI and HBL upon students. Prior to discussing the comparisons and their results, it is necessary to provide a discussion and overview of HBL.

2.4 Hypothesis-Based Learning (HBL)

HBL is an observation-based variation of the scientific method coupled with affective elements that allows students to rapidly experience and understand science as a rational process. HBL is deliberately designed to cause students to think about the world in a manner similar to professional research scientists. In this way, students get a hands on, 'driver's seat' perspective of what it actually means to perform scientific activities. HBL formalizes science as a process utilizing a method applicable to all audiences from elementary to university level, equally accessible across the spectrum of student ability. This method displaces the teacher as the sole source of knowledge to a position of a co-investigative partner, without large amounts of front-end-loaded content knowledge. Formal content knowledge is extracted from student experiments, coupled with additional content extension from other sources, and presented in a relevant context using a structured wrap-up at the end of the experiment. HBL was developed by Dr. Mark Rockley, et al., at Oklahoma State University in the early 1990's, and further developed in a five year Star Schools grant from the U.S. Department of Education from 2000 through 2005.

HBL, as a relatively new pedagogy, has enjoyed little peer-reviewed research or publications - as of this writing there exists a single peer-reviewed paper on HBL. In the discussion that follows, typical student terminological difficulties are used as a springboard from which the HBL process is developed. Thus, to understand HBL one must first understand some difficulties students have with the process of science, its use, and its terminology.

2.4.1 Student Difficulties with Scientific Terminology

After stating that science is performed according to 'The Scientific Method', science texts typically proceed to present 'facts' in a concise and orderly fashion without referring again to the method used to obtain them. Occasionally, ideas of historical interest are presented, but this is usually done without providing compelling reasons for students to see why those ideas are no longer believed. This presentation leads to the student opinion that science is really just a collection of facts, rather than a process for obtaining new or supplemental understanding of a situation or phenomenon. The other implication is that those holding outdated ideas were somehow less smart, educated, or sophisticated than current scientists. Students then have no understanding what it means to do science, that science is a way of revealing underlying patterns in nature, that new ideas with more explanatory power are more 'valuable' than any current ideas and are the end goal of science, that current ideas and theories must always be subject to verification and improvement (and thus replacement), or that they (like every other human on the planet) have been actively engaged in an attempt to understand the world around themselves since birth.

Student confusion regarding science may arise from at least two sources. Most scientists would likely suggest that facts arise as a side benefit of the process of science, a view at odds with the prevailing student view of science as a collection of facts. Also, students and researchers do not usually agree on the terminology used to describe the scientific process. Students tend to think of the colloquial usage of the words as an indication of meaning, while scientists are quite precise in their usage. To see how this misperception of science occurs, it is beneficial to contrast each group's terminological usage. In the discussion below, a 'hard science' (or empirical) perspective is assumed.

2.4.1.1 Hypothesis. When asked the meaning of the word hypothesis, most people indicate that it is a "guess", a "scientific guess", an "educated guess", an "idea of what is happening", or a statement of the outcome of some experiment: "When event X happens, the system will react with response Y." However, scientists assert that a hypothesis is a rational explanation of or reason for observed events that leads to testable consequences. This near-universal misunderstanding may be eliminated by thinking of a hypothesis as an explanation.

2.4.1.2 Prediction. Common wisdom asserts that a prediction is a guess about the outcome of some situation. Note that this does not refer to any specific underlying reason or cause, but is more a statement of "I think this will happen", and is nearly indistinguishable from the colloquial use of hypothesis. Scientists think of prediction as a logical consequence of an underlying hypothesis: "Because we understand the reasons for this system's behavior, we expect this specific outcome when things are changed in a particular manner." Note that specific reference is made to the explanation of the pattern! Also note that the predicted outcome is for a previously unknown future outcome - that particular experiment has not been done previously. Otherwise, the experiment would be grouped with those investigations that initially revealed the pattern and treated as background information that contributed to the hypothesis! Thus, when used by scientists, hypothesis and prediction are nearly always related using an "If , then " statement: "If the hypothesis (explanation) is true, then this (prediction) should happen."

2.4.1.3 Experiment. Experiment is usually taken by students to mean "When I do this, certain things will happen" - the experiment is what was done. Another common misuse of experiment is as a generic catch-all term for 'what happens when messing around with the equipment'. Neither 'experiment' has any particular relevance or reason for being done in a specific way, but is similar to the commonly held idea of prediction or observation. Thinking of experiment in this way provides no compelling reason to be careful when setting up or conducting the experiment - all that can happen is the experiment will show whether the prediction was 'right' or 'wrong', and will give no reasons for the behavior. Scientists have a totally different view of experiments. An experiment is a test of a predicted outcome that rests upon a hypothesis: "Because our hypothesis logically leads to this particular outcome, the best thing to do is to see if that actually happens." Again, this proposed experiment must be new, with the results unknown prior to the experiment to provide a fair test of the explanation. This view of experiment forces the scientist to carefully construct the situation and eliminate the influences of all things not covered by the hypothesis; otherwise, the test would be unfair. Nature will cause the results of an experiment to occur without error, and it is the responsibility of the researcher to insure that those results address the precise situation purportedly tested. What use is an experiment when the ideas it tests and potential sources of error are unknown?

2.4.1.4 Analysis and Reformulation. Once the results of an experiment have been collected, students are typically not inclined to consider them much further. Whatever occurred as the result of an 'experiment' may not have much to do with either 'hypothesis' or 'prediction' as used by the student. Analysis is usually thought of as seeing if the predicted outcome happened. If it did, students think: "I must have been right!" If not, then the most common student explanation proceeds: "I must have guessed incorrectly." However, scientists have a much more structured and particular set of activities they perform upon experimental results to derive additional meaning and check for internal consistency.

In the scientific sense, reformulation refers to a sub-process consisting of at least three distinct steps: data collection of the experimental information, data analysis which assigns meaning to the collected data, and evaluation to determine if the experimental results are consistent with the proposed hypothesis.

Data collection is the straightforward acquisition and collation of experimental information. Experiments produce data that must be interpreted or analyzed; no data is unequivocal. The researcher analyzes the data to be certain that no unwanted sources of variation have crept into the experiment, that errors have been eliminated or have been estimated, and that any patterns in the data have been extracted. Additionally, sense must be made of the analyzed results.

Evaluation continues the analysis of experimental data, in an effort to determine its consistency with the underlying hypothesis and the body of previously understood information. While a hypothesis may be adequate to explain a system's interactions, it must also be consistent with the collection of previously demonstrated hypotheses held to be true.

If the results are consistent with the predicted outcome and the underlying hypothesis, it may not be said that "This proves the explanation correct", since the very next experiment may reveal inconsistencies in the pattern. Thus, scientists advocate the use of "These results support the proposed hypothesis," which indicates a willingness to continue testing the explanation. Should the results and explanation be inconsistent, a crucial piece of information is learned: the hypothesis must be revised or replaced to make it capable of successfully predicting the outcome. It has become clear that the hypothesis is not adequate to the system's behavior! This is best indicated by "The proposed explanation was not supported", rather than the negatively connotated "The hypothesis was wrong." Instead of the expected groaning caused by this forced revision, scientists usually become quite excited by the prospect of learning something new. New interest is kindled by the challenge of trying to create a different way of explaining these new results in a manner consistent with past experience. One of the major things that sets science apart from most other human endeavors is this deliberate intent to subject our ideas to further scrutiny and willingness to replace or alter them should the need arise.

2.4.2 HBL Process Overview

Hypothesis Based Learning uses observational skills to initiate the scientific process and affective personal skills to support those engaged in the process. Instructional staff presents a carefully considered situation to the student, who is encouraged to explore. This situation will likely be a rich, multifaceted instance with many opportunities for students to follow their own interest.

During the exploration phase, many different aspects of the system present themselves. Careful investigation will reveal one or more aspects where one is forced to ask in wonder: "How in the world did THAT happen?" or "What in the world could cause that?" These aspects are discrepant events, so named because they are completely unexpected, and therefore objects of intense interest. Encouragement from instructional staff to follow discrepant events launches students in the HBL process, which is augmented by collaboration. Questions guide the student inquiry, while encouragement is used to maintain interest, enthusiasm, and classroom discipline.

The specific science process pieces of HBL are:

- Observations
- Discrepant Event and Additional Observations
- Hypothesis (Explanatory Hypothesis)
- Prediction
- Fair Test / Experiment
- Data Collection and Analysis

- Reformulation
- Communication
- Wrap-up

Individual process pieces are elaborated below. Similarities in terminology between the HBL process steps and the 'proper' scientific terminology above are apparent, and students are encouraged by instructional staff to develop an understanding consistent with their usage. Sample guiding questions are provided to illustrate the interactions between students and instructional staff.

2.4.2.1 Observations. The act of observation is an attentive investigation of a situation under study. Observation is more than "What did you see?" It includes active engagement of all senses except taste - tasting experiments or apparatus is never an acceptable risk. Observations include extensive written notes of things that occurred, as well as how they happened. Typically, students have difficulty with observations because they are equated only with the sense of sight. Truly, sight is a valuable way of collecting information about a situation, but other senses may (and should) be employed in their investigations. Oftentimes, the other senses allow crucial information to be gained. Thus, observation should deliberately include the senses of touch, smell, and hearing. A situation may change with time - smells may get noticeably stronger, heating may take place initially but then may seem to stop later, sounds may be produced that are repetitious or seemingly random.

Instruments other than the body may be used to collect information about a situation, such as when a ruler is used in measuring the length of an object. This highlights two types of observations: numerical and non-numerical. Numerical observations are numbers having significance in respect to some aspect of the situation: how many ice cubes are used, each cube's mass and volume, the temperature of the ice before, during, and after mixing. These observations are most likely to illustrate patterns and underlying relationships between pieces of the system when analyzed using mathematics or graphing. Non-numerical observations provide insight into those aspects of a system that do not readily lend themselves to numbers or mathematics: how did the color change, what smells were emitted and how did they change, how the experiment sounded, or if a noticeable thermal change was detected. Both types of observations are important and provide insight into the situation.

Observations may also be static or dynamic. Static observations are those that do not change with the passage of time, such as the size of an object, the color of a screen, or presence of a lid. Dynamic observations are those that change with the passage of time, and frequently are tied to the interactions of system components. Examples of dynamic observations include the time of an object's fall, the sound of a moving sheet of paper, loss of water as it gets heated, or changing colors as a result of mixing. Instruments may be used to make either static or dynamic observations, but are more frequently used when making dynamic observations.

To obtain the most useful observations, large numbers of observations are needed to get beyond superficial or trivial data to the interesting and insightful occurrences. One way to encourage specific types of observations is to specify a minimum number of different types of observations. "What", "How", and "Did" questions typically guide the observation phase.

Sample questions guiding student observations:

- What happened?
- What did the system do while you observed it?
- Did they system change in any way? If so, how did it change?
- How long did that take?
- Does this happen every time?

2.4.2.2 Discrepant Event. In HBL, the student is encouraged to concentrate upon their most intriguing observation. This observation may be related to others: if so, the set should be treated as a related single observation. All further investigation will concentrate on the discrepant event, which should be investigated thoroughly with additional observations specific to that discrepant event. Note that this encouragement effectively guarantees that many students will be pursing unrelated investigations - rather than being a hindrance, this feature of HBL is actually quite desirable as student discoveries are presented to all students in the wrap-up phase detailed below.

Questions used to determine appropriate discrepant events usually involve words like "most interesting", "strangest", "most unexpected".

Sample questions guiding student discrepant event investigations:

- What was the strangest or coolest thing you observed?
- Did you find anything you were not expecting?
- Was there anything really weird about this system?
- What surprised you?

2.4.2.3 Hypothesis. It is important for students to develop a rational, deterministic attitude when performing science: all things observed happen for one or more understandable reasons. These reasons proceed from everyday, real-world causes that do not require unusual interactions or the action of an unobserved agency. Thus, science becomes a game of figuring out the 'rules' that allow the unexpected behavior or the reasons that explain the discrepant event. A special rule or explanation for the discrepant event may be required, but it is most desirable to have as few independent and general rules as possible. Specific cases do not reveal general rules or patterns. Scientists usually suspect new rules invoked to explain specific cases - they desire a few (usually simple) rules with wide applicability, especially in physics.

Students should never lose sight of the fact that the investigation centers upon the discrepant event, so their hypotheses must address that set of observations. Other observations may have their own explanations. Whether the explanation is true in reality, it must be plausible and lead to testable consequences.

The best questions to elicit explanations involve “why” and “how”.

Sample questions guiding student hypotheses:

- Why did that happen?
- Is there any reason this should happen?
- I wonder why that is?
- What’s going on when this occurs?
- How did the system do this?

2.4.2.4 Prediction. Certain additional events should arise as logical consequences of the hypothesis advanced for the discrepant event. Students should concentrate upon the most telling consequence - that consequence which would affirm or deny the hypothesis. Without a testable consequence that may be evaluated with the equipment at hand, the process will stall and a different hypothesis must be advanced. Predictions assume the proposed hypothesis is true and investigate its consequences.

Predictions have three characteristics: they follow logically from the hypothesis, they must be testable with the equipment provided, and they must address situations the student has not previously observed. The lack of equipment to test a prediction does not reduce the validity of a prediction or hypothesis; however, it may restrict student investigations to those hypotheses that are actually testable using available equipment. Students cannot have previously observed the situation involved in a prediction, since they have information about the outcomes that prejudices what they indicate should happen. Predicted outcomes must be unknown at this point in the HBL process to be fair to the hypothesis.

It is common for students to be able to make observations and then immediately predict an outcome under altered circumstances. This mode of thinking is acceptable, assuming the student is asked to provide the underlying reason or hypothesis for the predicted behavior prior to performing an experiment. Since everything beyond this point in an investigation rests upon the strength of the hypothesis, establishing the rules underlying a situation is crucial even if predictions precede hypothesis.

Guiding questions for predictions involve future tenses or words that alter the amounts, sizes, or timing of system aspects: "What will", "What if", and -"er" suffixes (larger, quicker, hotter, etc.). It is also helpful to insure that the prediction proceeds from the explanation: "This is because the hypothesis is true, right?"

Sample questions guiding student predictions:

- Is there something else that should happen if your hypothesis is true?
- Since your story explains why this happens, what would happen if an aspect of the system were altered?
- What would you expect if this characteristic were reduced?
- How would things change if you did this?

2.4.2.5 <u>Fair Test / Experiment</u>. A fair test is a series of experimental steps designed to test a prediction. There are three criteria for a fair experiment: it must test the prediction, it must be done with the available equipment, and it must test the influence of only one variable at a time. Experiments involving multiple simultaneous variable changes are to be avoided, as they are difficult to interpret. Students should be encouraged to develop the habit of explicitly stating all steps in the experimental process, which will help in error analysis and control of variables.

Questions about the experimental process center on actions and "How" ideas: "What steps", "How would you", and "Next, ...".

Sample questions guiding student experiments:

- How will you see if the prediction actually happens? Be specific.
- Is there any way you could see if your prediction happens?
- What has to be done to see if this works?
- Are there any other things happening that could interfere with your results?

2.4.2.6 Experimental Results: Data Collection and Analysis. After performing the experiment, results are collected, organized, and meaning is assigned to them. Mathematics or graphs may be used on numerical data to extract patterns. Students must take care to interpret the data in light of the hypothesis and the variables controlled in the fair test. While relatively difficult, this process is one of the most crucial in HBL: the deductions from experimental outcomes determine whether a hypothesis is capable of providing insight into the functioning of the system. The quality and strength of experimental evidence is crucial in deciding whether adequate support for a hypothesis exists.

Summative and inferential meaning questions are important to this activity: "How", "What happened", or "This indicates...".

Sample questions guiding analysis of experimental outcomes:

- What happened when your experiment was performed?
- Does this result tell you anything about your prediction or explanation?
- Does this result support your explanation?
- Is this result consistent with your prediction?
- Could anything else have caused this?
- Would mathematical analysis reveal if your prediction occurred?
- Would mathematical analysis assign meaning to your results?

2.4.2.7 Reformulation. As a result of the experimental outcomes analysis, the hypothesis must be evaluated: is it capable of explaining the outcomes by itself? If so, the hypothesis is supported and should be shared with others. If not, the hypothesis must be altered to bring it into agreement with the new results. This reformulation is a hallmark of science: the outcomes of deliberate investigations decide which hypotheses are retained. Unsupported hypotheses that cannot be altered to accommodate the data must be eliminated.

The decision to reformulate is a trinary choice. If the results are consistent with the prediction and hypothesis, no reformulation is necessary - the proposed explanation is satisfactory. If the results are not consistent, some alteration of the hypothesis is required. However, the results may be consistent with the hypothesis and prediction but indicate a change that would improve the hypothesis or extend its applicability. In the normal science process, reformulation leads to initiating the process anew from the hypothesis phase using the improved explanation.

Reformulation questions concentrate upon comparisons between the predicted results and the actual results, while allowing room for explanatory improvement: "How does this compare with", "Is it consistent with", or "How might this be improved". If the old explanation is not supported, a new explanation must be put forward, although it may not necessarily be tested by the student.

Sample questions guiding reformulation:

- Does this explanation explain the results attained by the experiment?
- If the explanation wasn't supported, how might the explanation be changed to explain both the discrepant event and this new data?
- If the old explanation cannot be altered to accommodate the new data, is there another reason that would explain the discrepant event and the new data?

2.4.2.8 Communication. Sharing results is of crucial importance in science, as it allows others to benefit from an experiment without the necessity of doing it themselves. Additionally, it conveys to others results and explanations they may not have had access to or thought of doing on their own. This sharing of information builds communities and inspires self-worth among students, giving value to their efforts and rewarding their hard work. Additionally, content is reinforced by viewing the information from multiple perspectives.

The overall thrust of questions guiding the communication phase is "Of the things that were learned as a result of this investigation, which are worth sharing with peers or the community in general?" Successes are just as important to share with others as apparent problems. Thus, "What" and "How" questions designed for a summation of the experimental activity are effective.

Sample questions guiding student communication:

- If your explanation is supported, what did you learn worth sharing with others?
- If the explanation was not supported, how would you tell others that it is faulty?
- What have you learned about the system?
- How were you able to explain what the system did?

2.4.2.9 Wrap-up. The final phase of the HBL process organizes student experiments, obtains workable explanations for observed aspects of the system, extracts content from student investigations, and injects additional formal content. Instructional staff present information about significant lines of inquiry to the class, with opportunities for students to present their own work. Students are encouraged to ask questions and interact during the wrap-up. As student investigations and questions are discussed, content may be injected into the discussion - more appropriate terminology, ideas with additional explanatory power, or completely new ideas that impact upon the experiments in some manner. In this way, a solid experimentally derived basis is developed, upon which students may build a more complete understanding of the ideas and concepts presented in the activity. This presentation of concrete hands-on experience prior to abstraction of the situation towards a more formal understanding gives students the necessary background to place the abstractions and establishes clear importance of the experimental data, analysis, and peer communication. In short, students firmly ‘buy in’ to the investigation.

2.4.3 HBL Class Overview

HBL students enjoy the freedom to follow their own interests while pursuing science content via the above process. HBL laboratory content largely eliminates lecture-type interactions, replacing them with laboratory activities and interactive classroom activities. The HBL content is self-contained and provides students access to all needed information, such as definitions, background information, and limited content through the class website or information distributed in class. Laboratory equipment is similar to that used in PBI - equipment used is modest and relatively available at low cost.

From the student perspective, HBL laboratories are initiated with an instructional staff-led activity called an initiating event. This initiating event is a situation chosen to illustrate a particular content area, theme, or type of outcome. Initiating events are situations where students get to observe specific activities or outcomes pertinent to a particular line of investigation. Major features of initiating events are that they must: provide access to several potentially discrepant situations or outcomes, be general and allow many types of investigation, and be related in content to the area under investigation. Student investigations of the discrepant event may be limited or enhanced through appropriate choice of available equipment. Typical initiating events for the Physics 1313 content chosen for this dissertation were extracted from actual activities performed by PBI students as a result of following the PBI laboratory manual.

Students using HBL attend class having previously read the current background information. They are also given information regarding the initiating event they will observe in class, such as the equipment to be used and its initial state. However, all HBL laboratory material has been carefully written to avoid providing discrepant event outcomes, observations, or answering content-dependent questions arising from previous or current laboratory activities.

Students are led through the initiating event by instructional staff, who typically incite discussion and pose thought-provoking questions. It should be noted that all students witness the initiating event at the same time, and then are encouraged to investigate it and related situations in small groups. After performing their own investigations, students are provided exposure to other student investigations through the wrap-up discussion led by the staff.

2.4.3.1 HBL Laboratory Write-up Overview. Upon completion of every experiment, students submit a process-oriented laboratory write-up. This write-up is useful in many ways: it may serve as a student guide through the HBL process, the writing activities help students to formalize and reflect upon their knowledge, and it allows consistent grading of student work. This form serves functions similar to the notebooking activities encountered in PBI instruction. A sample write-up form is included in Appendix C with the HBL course materials.

2.4.3.2 HBL Student- Student Interactions. HBL students are grouped into small, collaborative groups composed of between 2 and 6 members. Students pursue their own investigations at their own pace, but are encouraged to collaborate with other group members. Situations frequently arise where students need help in making measurements, collecting data, or setting up experimental apparatus where they need help from other group members. Should a student not find anything interesting enough to warrant investigation, student group interactions allow additional exposure to new situations that they may find interesting.

Students are frequently observed to help one another with difficulties encountered during the course of their investigations. Students help others create explanations and hypotheses, design experiments, interpret experimental outcomes, conduct experiments, present interesting situations, and discuss material related to the laboratory.

2.4.3.3 HBL Student-Instructor Interactions. Students interact with HBL instructional staff in many ways. The most common of these is through Socratic interactions while students pursue their investigations. These interactions are designed to lead students through the HBL process, verify appropriate logic use, and clarify or extract meaning from situational outcomes. These interactions allow staff to obtain feedback from the groups and track the pace of students through the content, as well as providing opportunities for fostering collaboration or conveying encouragement. During these interactions, staff collect information regarding student investigations that may be used either in other student interactions or in the wrap-up.

Instructional staff provide access to other student investigations either through personal discussions, group interactions, or the more formal wrap-up activity. Wrap-ups of student investigations are used to provide exposure to common modes of student investigation, student hypotheses, major outcomes, or particularly interesting situations. Injection of context-appropriate science content commonly occurs during the wrap-up, as student investigations generate it, or as it becomes apparent it is needed as the basis for future models and explorations.

Finally, students interact with instructional staff through 'lecture' activities. Note that these are not traditional lectures, but rather opportunities for staff to present major content items through a series of quite short (typically 5 to 10 minute) presentations followed by opportunities for students to immediately and collaboratively address the new content in problems. Students present their solutions to these exercises, and benefit from the resulting discussions. Frequently students are called upon to present alternate explanations or problem solution strategies.

When using HBL, instructors adopt the role of mentor and co-investigator. The utility of the staff to the student lies in keeping the student focused on the appropriate process step, providing opportunities for the student to discuss their results, fostering collaborations with other students, providing additional observations, clarifying experimental contexts, and in guiding students out of tricky or difficult situations. All students, regardless of their interest or experimental situation, are investigating situations with intent to understand them more deeply. As an instructor guides them through the HBL science process, students internalize the process and questions they may ask of themselves when they reach an investigational impasse. Through HBL, staff become less like 'information authorities' and more like 'intellectual safari guides': they take the students to where the science 'big game' lives, provide the tools needed and administer their proper use, help students approach a rich and interesting situation, provide support for the acquisition of new knowledge, and allow sharing of the experience with student peers.

2.4.4 Creation of HBL Experiments from PBI Curricular Content

Prior to developing any HBL content, the author utilized PBI and Socratic student interactions from the fall semester of 1998 through spring 2002. During that interval, and the year-long HBL development interval from summer 2002 through summer 2003, the author was an instructional staff member for every offering of Physics 1313, a total of 13 course sections. Course sections, due to instructional staff, space, and equipment constraints, were limited to maximum enrollments of 25 students. The author was the instructor of record for the final 11 sections, and has remained so through the present semester (fall 2005).

Since the HBL pedagogy is so different from that of PBI, the development of HBL laboratory investigations becomes a crucial issue for this dissertation. It may be expected that this mapping of PBI content to HBL is quite difficult; in reality, it is not overly challenging provided the following conversion strategy is used. This section discusses the selection and creation of HBL laboratory material from the PBI content.

Initially, content from PBI was selected for conversion to HBL. The selection basis was partially experience, partially expediency. The experience basis was used to select PBI material that had been used at least two semesters at OSU by the author. This criterion was used since the author felt it important to be fair to PBI by adequately mastering the interactions and questions arising from the module's content prior to using it in an unfamiliar manner. Additionally, only experience reveals how a typical class of students will progress through the PBI content. This understanding is irreplaceable, since the pace of the PBI students determines the number and type of laboratory investigations performed by HBL students. Expediency was used in the sense that it was initially felt that some content would be more easily converted than others. However, after conversion, it became apparent that HBL is flexible enough to accommodate any of the PBI content with minimal alteration.

2.4.5 PBI to HBL Content Conversion Strategy

After content has been selected for conversion to HBL investigations, it must be examined carefully to insure that the major content ideas are represented in the final HBL laboratories. This was done using the following process:

1. Experience the entire PBI module in the same manner as the student.

2. Carefully review each experiment within the PBI module, identifying intended lessons or content pieces.

3. Examine each single PBI experiment and identify where it fits into the overall physical investigation strategy. Create a sequence of investigations for the entire module; this sequence will likely be the same for the HBL content.

4. Identify the instance within each PBI experiment of most crucial value for the goals of the module. Maintain a list of investigations and considerations related

to each experiment. These will likely arise during the HBL investigations done by students.

5. Recreate that single experience as an HBL initiating event using the same major features of the PBI experiment. Appropriate initiating event choices assure that most students investigate related topics.

6. Constrain the available equipment and initial interactions to limit HBL investigations to those mirroring the PBI experiment. Equipment constraints limit student investigations to content areas similar to those in the initiating event, assuring that students investigate related situations. Assure that sufficient equipment is available to facilitate investigations into closely related material listed above.

7. Administer the new HBL experiment to a real group of students and evaluate whether the PBI goals were served using the new HBL investigation. Consider whether changing the equipment constraints would benefit the HBL activity in more closely mirroring the PBI experiment. Revise and repeat this step as necessary.

8. Repeat the above sequence of steps for the remainder of the PBI module content. Limit the number of HBL activities to the same number of class days as the PBI module.

This strategy was used in the development of HBL content from modules in PBI. The entirety of the HBL course content arose from the above considerations.

2.4.6 Physics 1313 HBL Content

During the summer of 2002, PBI module content was selected for inclusion in the current study. The PBI modules and sections chosen are illustrated in Table 2.1. Note that excluded PBI sections are problems, exercises, or activities not used.

Note that every effort was made to insure that each pedagogy spent equal times on each conceptual module. Slight discrepancies exist due to several factors, including a short training period for students in HBL. Additionally, the PBI students occasionally needed an extra class day to achieve certain checkpoint objectives. Any remaining 'time-on-content' issues clearly favor the PBI pedagogy. These timing differences were judged to have small (if not insignificant) contributions to student performance, and have been ignored in all aspects of the studies conducted in this dissertation.

PBI module content was translated into HBL laboratories and activities during the fall 2002 semester. This HBL content was used during the fall 2002 and spring 2003 semesters in an evaluatory capacity. Revisions of the HBL laboratories and activities were made during the spring 2003 semester and during the summer of 2003. At that time, it was felt that the existing HBL content was sufficiently robust to be fairly compared to the PBI curriculum.

2.4.7 HBL Course Materials

Material developed for the HBL sections of the course is available for inspection in Appendix C. Appendix C includes all HBL laboratories used during the study, as well as all 'lecture'-type activities. The laboratories are reprinted from the HBL course website created by the author.

Note that the structure and features of the HBL laboratories follow a well-defined pattern. This pattern was decided upon for two reasons important at the time of development. First, the structure was chosen to facilitate ease of interpretation by students. Students should expect similar types of material to always appear in the same section, providing internal consistency. Second, at the time of development, the author was in the midst of collaborations with educators outside the scope of this dissertation. Using the structure, these instructors could use the HBL laboratories in stand-alone fashion in their own applications. Laboratories having this structure

HBL Course Content Development Information

Module	PBI Sections	Number of Class Days	Number of HBL Activities
Astronomy by Sight	§1 (1.1 – 1.9) §2 (2.1 – 2.3, 2.7) §4 (4.1 – 4.6) §5 (5.1 – 5.11)	8.5	7
Light and Color	§1 (1.1 – 1.6) §2 (2.1, 2.3 – 2.9) §4 (4.1 – 4.5) §5 (5.1 – 5.4) §6 (6.1 – 6.6) §7 (7.1 – 7.6)	11.5	11
Heat and Temperature	§1 (1.1 – 1.7) §2 (2.1 – 2.3) §3 (3.1 – 3.5) §4 (4.1 – 4.12) §5 (5.1 – 5.4) §6 (6.1 – 6.5) §7 (7.1 – 7.5)	13	13
Electric Circuits	§1 (1.1 – 1.14) §2 (2.1 – 2.7) §3 (3.1 – 3.10) §4 (4.1 – 4.12)	10	9

TABLE 2.1. PBI module sections used in the development of HBL content, and a comparison of the number of class days per pedagogy.

could simply be reproduced and administered to students without conveying unfair advantages.

2.4.8 HBL Laboratory Structure Overview

A brief overview of the HBL laboratory structure is presented here, to facilitate comprehension of the laboratories and the structure's intent.

2.4.8.1 Background. Material in this section is intended to provide the concepts (and their contexts) encountered during the laboratory. Definitions, concepts, terminology, examples, and other information relevant to the lab are found here. Information in this section is presented in a general way, so as to not lead the student towards its use in their experiments. This section presents material similar in style and intent to the more didactic sections of the PBI manual.

2.4.8.2 Equipment. All equipment available to the students is listed in this section. The equipment has been deliberately constrained, as noted earlier, to limit student investigations into areas within the laboratory's intent. Students may use supplemental equipment only after discussing their request with a staff member. This section is also useful to instructors needing to obtain the necessary equipment for their classes.

2.4.8.3 Initiating Event Setup. This information is useful to both students and teachers, as it specifically discusses how the equipment used in the initiating event should be set up and used. Usually this section discusses only the initiating event - students are free to pursue other uses of the equipment, but all students will observe the initiating event with this common initial state.

2.4.8.4 Initiating Event. Students will observe the equipment, set up as indicated above, as it is used in the context described in this section. The initiating event is usually a series of instructions regarding the use of equipment, coupled to a series of questions used to remind students of the HBL process. The initiating event frequently has many discrepant features and opportunities for student investigation.

2.4.8.5 Required Submissions. All student laboratory work will be submitted to instructional staff on a process-specific worksheet. This section's utility is to specify any additional calculations, data representations, or other activities that must accompany the laboratory worksheet. Students reading this section prior to class know the expected outcomes of the laboratory, allowing opportunities for discussion prior to submission. Material in this section can also serve to direct students into investigations serving curricular needs: for example, it can insure that students complete a laboratory and a specific kind of calculation that they may have otherwise missed or neglected to investigate. The intent behind these additional requirements is to allow free student investigation while simultaneously presenting a need to understand particular curricular objectives. These objectives may be met either through explicit investigation in that area or through collaboration with student peers.

2.4.8.6 That's odd.... Information in this section typically centers upon commonly encountered unusual student observations. The intent of this section is to present thought-provoking situations and observations to the student without presenting them as a portion of the initiating event. These strange observations could be used by students to spark interest in an area, or to help students who are stuck without interest in the initiating event.

2.4.8.7 Food for Thought. The intent of this section is to provide guiding statements or questions designed to specifically address some of the material encountered as a part of the laboratory investigation. This material is frequently used to challenge students to create mathematical models, examine important conceptual problems, remind students of previously understood models, or present potentially confusing or contradictory positions for resolution.

2.5 A Comparison of PBI to HBL

Despite the fact that both PBI and HBL are inquiry-based pedagogies, they are quite different from one another. This section discusses some of the similarities and differences between PBI and HBL.

2.5.1 Similarities

PBI and HBL are similar in many regards. Both use hands-on situations to encourage students to become interested in the material and actively engaged in the investigations. This 'brains-on' feature has been discussed in the literature at length as a necessary precursor for student learning and conceptual change. 'Low-tech' equipment is featured in both pedagogies: it is not necessary to have expensive or unusual equipment to illustrate and investigate most physical phenomena. In fact, having complicated equipment may actually cause more conceptual problems than it solves, aside from being expensive.

Interactions between the students and instructional staff are similar for both PBI and HBL. HBL, as used in this dissertation, utilizes the same effective Socratic interactions that PBI uses. Although HBL is not specifically committed to using Socratic interactions, personal experience has shown them to be most effective in combination. However, while PBI is exclusively Socratic, HBL interactions are more flexible in style. The author estimates that approximately 80% of his HBL student interactions are Socratic. The remaining interactions allow instructors the freedom to remind students of information they have, suggest further investigations or strategies, or react to student questions. This has the added advantage of allowing students to feel more like the instructor's investigatory peers rather than being 'question answerers'. In this author's experience, students were most dissatisfied with this aspect of

PBI. The constant use of questioning can infrequently be an emotional hindrance in student interactions, a problem addressed by this flexibility.

In both pedagogies, instructors are likely to be perceived by students as co-collaborators or investigatory peers. In part this happens because the evidence for a conclusion drives the models and deductions, rather than an appeal to abstract principles or authoritarian argument. Additionally, instructional staff enjoys a transition from the sole (infallible) source of information towards mentoring roles. These changes in student-instructor interaction promote many positive changes in the class culture, not the least of which is that appeals to authoritarian 'knowledge' are not useful in science. Finally, education students see that there are effective responses to questions when they do not know the answer: the process of science can help in addressing the problematic question, rather than allowing no acceptable recourse.

2.5.2 Differences

For all the similarities between PBI and HBL, there are many differences. The largest of these differences is fundamental. In PBI, students are guided through an investigation where the structure of the investigation is given in the form of a laboratory manual. Students rarely see that the investigation itself has a structure that they can use on previously unknown situations. As they follow the investigation, students are passive in the sense that they are engaged in answering questions that they themselves are not trained in asking. Stated another way, the laboratory manual does the structural thinking for the student. It is never clear to the student, nor is it ever made clear, why a particular investigation proceeds along certain lines of inquiry. This situation is in stark contrast to students trained in HBL. Student interest is the driving force in all laboratory investigations. This interest causes students to seek for answers to questions raised by their own curiosity. The guiding principle in this desire for answers is the science process used by HBL in addressing new situations, including situations arising outside class. Students familiar with HBL understand that they have the freedom to speculate upon the causes of a system's behavior, and the obligation to decide if they actually account for new behavior. While the details of the tests used will be particular to the situation and questions asked, HBL students are capable of creating new situations that allow them to decide upon the behavioral causes. Note that this flexibility extends to all new situations, even ones they are not specifically interested in or that they do not find discrepant. Frequently, the HBL process allows students to pursue many different investigations during the course of a single laboratory. In the author's experience, this commonly translates into highly motivated students performing between three and seven distinct (and complete) experiments in a two hour timeframe. The HBL process guides the student's quest for answers. PBI students do not enjoy this advantage.

Another difference between PBI and HBL has been central to this discussion, but not yet addressed. That is, PBI is a highly-directed pedagogy, while HBL inquiries are guided by science process. This places each pedagogy on opposite ends of the 'spectrum of inquiry'. Much study of directed inquiry exists, and student understanding shows favorable responses to it. Open inquiry, on the other hand, is not nearly so well supported in the literature. In part this may be due to the relative difficulty of assessing which open inquiry features are responsible for student gains, or may simply be due to the common conception that less-structured investigations cannot work as well as structured ones. Regardless, some educators seem less likely to embrace open inquiry methods due to the relative absence of evidence of their effectiveness.

Students following PBI investigations may lose interest with time. This loss of motivation could be due to becoming overwhelmed, 'burnt out' with the repetitive nature of the laboratory manual, or that they become embroiled in the minutiae of an investigation in which they have no personal investment. HBL students, however, are personally involved with every decision and investigation performed. They have 'bought in' to the investigation on a personal level very early in the process and become unwilling to not see an investigation through. Coupled with ongoing encouragement from instructional staff, this creates a powerful incentive to explore and continue a line of inquiry. The author estimates that, at some time during any given HBL semester, a minimum of 60% of the students seek him out and express their new-found joy in investigating their world. Paraphrasing the student conversations, it is most common to hear something like: "This process is amazing, but I can't turn it off! I keep seeing new things. I wonder about them and try to explain them. I never have been able to do that before!" This author takes statements of this nature to be the ultimate student compliment.

Finally, students following PBI remain in lockstep throughout the module. Instructors know where to expect conceptual difficulties and problems, making class management straightforward. Few unexpected surprises arise due to the structure students follow. Individual creativity is rarely seen or rewarded throughout an investigation. In contrast, HBL students tap into their creativity at every opportunity, regularly creating serendipitous situations and unexpected outcomes. This creates an atmosphere of excited engagement. The downside of this situation is that classroom management could be seen as akin to herding cats. Students rarely encounter the same experimental situations or outcomes and must be periodically regrouped. This is the major function performed by the HBL wrap up. Students get an opportunity to encounter the results of other student investigations while sharing their own. Additionally, students encounter major results which become the underpinnings of future investigations.

CHAPTER 3

REVIEW OF SELECTED LITERATURE

3.1 Overview of the Literature Review

As of this writing HBL is represented in the literature with a single published paper.[24] One additional paper, although not explicitly concerned with HBL, was published during the continuing development of HBL and is reflective of many of the issues leading to its creation and development.[25]

This quite limited literature is due to two factors. HBL is a relatively new pedagogy, developed within the past decade. Without attendance at one of the workshops sponsored by the development group or without enrollment in and completion of the online workshop designed to teach HBL[26], teachers are unable to access training in HBL and would remain completely ignorant of the pedagogy. Thus, the base of teacher support for HBL is severely limited. Restricted HBL use certainly manifests itself in the dearth of publications. The relative newness of the pedagogy contributes to the second problem, namely that very little research has been done on HBL with an eye towards publication. Although the HBL4U project development team has collected much data on workshop participants since 2000, none of that data has been formally analyzed and published in refereed journals. Some data and analysis exist in the summative reports of the external reviewers of the HBL4U project. These reviewers from the University of New Mexico have created extensive reports for submission to the U.S. Department of Education in support of the project, but these reports have most likely not been reviewed by the science or education communities at all. This dissertation will not consider these summative reports, as they do not form part of the peer-reviewed literature.

Given the scarcity of published literature on HBL, the strategy of this literature review is to establish and support some of the main tenets of HBL, placing the HBL pedagogy on a foundation of peer-reviewed research. This support is augmented by reviewing some of the sex/gender-related issues relevant to the study populations. Additionally, it is important to establish the relevance of problem-solving literature to the 'wrap-up' used in HBL. Finally, the instruments used to collect data for analysis must be discussed. Instruments and their use will be discussed in Chapter 5. Thus, this Chapter's literature review is subdivided into four sections: HBL Papers Review, Collaboration/Cooperative Learning Review, Problem-Solving and Wrap-Up Review, and Sex and Gender Issues Discussion

3.2 HBL Papers Review

VanDorn[24] discussed HBL in two contexts. First, HBL may be used to extend highly-directed inquiry teaching pedagogies and curricula (such as Science and Technology Concepts for middle Schools (STC)) into the less structured realm of open inquiry. Second, VanDorn addresses many teacher concerns with adopting HBL in their own classes.

HBL is advocated as a relatively accessible extension of directed inquiry instruction. An overview of the HBL process is given, with notes on utilization. Unfortunately, this discussion is quite brief and does not explicitly discuss the transition from directed inquiry investigations towards the much more open HBL inquiry. However, it should be noted that an effective and relatively comprehensive discussion of this topic was likely beyond the scope of VanDorn's paper and would take the form of a small text.

Interestingly, teacher concerns seem to center on classroom control and content. Students (and by inference, their teachers) are judged by their performance on national standardized exams. These results lead to trepidation on the part of the teacher, since he must demonstrably cover a set of material outside his control.

Any change in the established instructional method must clearly provide benefits not currently present. Without reasons to believe advantages exist (and that they are easily attainable), teachers are reticent to put themselves and their students 'at risk' by attempting something new. VanDorn attempts to allay these concerns, and is perhaps more successful than 'ivory tower academic' authors because she is a current practicing member of her paper's audience.

In a compelling metaphor, VanDorn discusses the nature of science and her answer to situations arising when students ask questions outside the content knowledge of the teacher:

> *"Scientists know that science is like a net thrown over reality to capture and control it. But the net has more space than twine. Much slips through. There is always more we don't know than we do know. But we learn more over time. How? We read about what is known scientifically, and we do the process along with our students. We become co-learners with our students."*

In short, VanDorn argues that HBL presents an opportunity to change the culture of the classroom to one of collaboration and co-learning with the teacher, and that HBL allows teachers and students to support a habit of lifelong zest for learning.

Montes and Rockley[25] conducted four years of secondary school teacher training workshops and report the results of an exercise given to participants designed to investigate the relative utility and merits of inquiry-based chemistry laboratory instruction. Teachers attending the workshop were discovered to use verification laboratories frequently in their chemistry courses: not more than 15% of the participants had ever tried inquiry instruction, and only 5% reported inquiry use more than once per semester. Teachers were asked to provide advantages and disadvantages of traditional verification laboratory exercises. Advantages and disadvantages listed by teachers are summarized in Table 3.1.

Advantages And Disadvantages Of Traditional Verification Laboratory Exercises

Advantages	Disadvantages
Easy to time, prepare, and grade	Easy to copy or make data
Easily extensible to large class sizes	Labs are boring, inflexible, the same for all students, and lack excitement
Easy to supervise and help students	Students are mentally passive, do only what is needed, and do not learn from unexpected results
High likelihood of student success	Labs do not require creativity or exploration
Instructor knows experimental outcomes	Labs do not teach problem solving skills
Labs are more structured, quiet, and less controversial	
Students learn to follow instructions, lab equipment, and procedures	

TABLE 3.1. Relative advantages and disadvantages to traditional laboratory instruction as identified by practicing teachers surveyed by Montes and Rockley.

Upon reflection and analysis, every disadvantage of verification laboratory exercises primarily affected students, while nearly every advantage favored the instructional staff. The single set of advantageous student learning suppositions was actually seen to be lacking or disadvantageous. Thus, chemistry laboratory instruction apparently sacrificed student learning in favor of the convenience of the staff and instructional expediency. One of the results of this analysis was that teachers became much more willing to explore and consider the use of inquiry-based laboratory activities. Ultimately they became convinced that the perceived ‘disadvantages’ of the less-structured inquiry environment were actually advantages for the student!

Despite this analysis, teachers are still reluctant to change their instruction. Montes and Rockley argue for a change in the educational culture from which education students receive their training:

> *"It is not unreasonable to believe that, despite exposure to the advantages of the inquiry-based approach in their teaching methods courses, many traditionally certified teachers also ultimately adopt the style in which they were taught science. Since the vast majority of teachers learned science using the verification approach, they will most likely employ this same approach in their classes."*

This author would like to report that, as a result of his collaborations with Montes and Rockley in 2002, physics secondary teachers report nearly identical inquiry use and expressed the same set of perceived instructional 'advantages' and 'disadvantages'. This result was not published, but is certainly in agreement with their findings. Despite exposure to these ideas, only a small fraction (estimated to be less than 20%) of participating teachers adopted any long-term inquiry-based instruction in their classrooms. It is this author's belief that an 'inertial' effect exists against instructional change, in favor of convenience and ease despite demonstrable difficulties with verification activities.

3.3 Collaboration Review

An extensive literature analyzing collaborative efforts and benefits exists. Much of the research on cooperative learning in science education has focused on elementary or secondary school children, although University students are being studied more frequently in the literature. At least partially as a result of this research, instructional methods are changing in primary, secondary, and post-secondary education.[1,15–17,27,28]

Undergraduate instruction has been seen to benefit from the following 'good practices'[2]:

1. Encourage contacts between students and faculty.
2. Develop reciprocity and cooperation among students.
3. Use active learning techniques.

4.Give prompt feedback.

5.Emphasize time on task

6.Communicate high expectations.

7.Respect diverse talents and ways of learning.

These practices are clearly not only beneficial to University students, but to students in general. These 'good practices' emphasize communication (points 1, 2, 3, 4, and 6 above) and group and social interaction (points 1, 2, 3, and 7 above). The role of instructional staff is more managerial than oratory in style (points 1, 2, 4, 5, and 6 above). Many 'active learning techniques' are available to instructional staff, most having as their central feature the grouping of students into collaborative teams. This 'cooperative learning' strategy has indicated several lessons important in the context of this dissertation and HBL in general.

Cooperative learning methods require students to work in groups having similar goals. Cooperative learning groups are broadly divided among structured and unstructured groups. Structured cooperative learning groups are assembled with care by the instructional staff with regards to number of students, student group placement, student roles within the group, task structuring, and other issues. Unstructured groups are less organized by instructional staff or are self-organized. Group structure can influence the groups' outcomes heavily, causing them to work effectively or not at all. [29–33]. In general, structured groups outperform unstructured groups, although both outperform individual or competitive strategies.[30] These gains occur despite reductions in course content and increases in class time spent on collaborative investigations.

Cooperative learning can be contrasted with competitive or individualistic strategies of learning[29]. A meta-analytic survey of approximately 400 cooperative learning studies from 1897 to 1988 was conducted by Johnson and Johnson[30]. Subjects in this analysis spanned the academic range from University (nearly 40%) to kindergarten, and all academic content areas (including science) were represented in the analysis. Cooperative effort among students was seen to produce higher academic achievement and productivity than either individual or competitive efforts. It should be noted that Johnson and Johnson estimate the significance level of their study to be approximately $p < 0.00001$. The analysis caused Johnson and Johnson to conclude:[30]

> *"A conservative interpretation of the overall data would be that participating in cooperative groups does not hurt, and often facilitates the achievement of high-ability individuals, and clearly benefits the achievement of medium- and low-ability individuals."*

One explanation for the enhanced performance of students in cooperative learning groups is that they act together to 'co-construct': students collectively create the knowledge and methods used in attaining a common goal. College students working in cooperative learning groups have consistently been observed to produce physics problem solutions superior to matched problem solutions by the best individual group member. On a six-exam study, it was determined that the group solution was statistically different (and superior) to the matched best student solution at the $p < 0.05$ significance level on one exam and at $p < 0.01$ for the other five exams. Group solutions clearly include work from all members (even low-ability students), indicating that the solutions do not simply originate from the strongest member.[33,34] No clear consensus exists regarding the mechanism underlying the construction of superior group solutions. However, Brown and Palincsar[35] postulate (in their extensive summary of cooperative learning research) that the distribution of thinking and involvement in the problem's structural dissection among all group members may account for the group's success.

3.4 Wrap-Up and Problem Solving Review

The acquisition of the skill to effectively solve problems, especially in physics, has been studied in many contexts. These analyses typically involve the relatively serial skill enhancement through a series of stages from 'novice' to 'expert'. Below is a brief overview of several models of problem-solving skill acquisition.

Dreyfus and Dreyfus[36] model general problem solving skills as an increasingly advanced series of skill-steps from novice to expert. In this model, the learner moves from a 'case-by-case' problem-solving approach towards strategies guided by patterns, underlying principles, and experience:

- **Novice**: learns to recognize various objective factors and features relevant to the skill and acquires rules for determining actions based upon those facts and features.

- **Advanced Beginner**: Performance improves to a marginally acceptable level only after the novice has considerable experience in coping with real situations. Uses context-free facts.

- **Competence**: With more experience, the number of recognizable context-free and situational elements present in a real-world circumstance eventually becomes overwhelming. People learn a hierarchical procedure of decision making.

- **Proficiency**: Intuition is neither wild guessing nor supernatural inspiration, but the sort of ability we all use all the time. The proficient performer, while intuitively organizing, will still find himself thinking analytically about what to do.

- **Expertise**: An expert generally knows what to do based on mature and practiced understanding. When things are proceeding normally, experts don't make decisions; they do what normally works.

This outlook is consistent with the work of Larkin, et al.[10], which indicates that students tend to utilize nearly-random equations or the stated (and mostly useless) details contained in a problem's wording, rather than the physics principles and experience used by more advanced problem-solvers, in attempting solutions. Novices seek equations and numerical solutions prior to developing the underlying principled conceptual frameworks that experts use. It is noteworthy that Larkin formally establishes a pattern for students to be taught problem solving: collect and analyze in detail the processes used by expert problem solvers, abstract those processes to general cases, and explicitly instruct students in the use of these processes. Here it is implied that the student may not easily learn the processes without the intervention of an expert problem solver (or someone who understands the process).

In regards to physics problems, Heller and Reif[37] assert that without a detailed understanding and description of the physics underlying the problem students will likely be unable to successfully solve problems. The 'physics description' must come before a search for the mathematics!

In mathematics problem solving, Alan Schoenfeld[38,39] advocates a 'heuristic' approach. The job of the instructional staff in this view becomes development, teaching, and implementation of a set of heuristics coupled with a nearly 'mechanical' problem solving strategy. Students use known heuristics to recognize the problem's underlying principles, while being guided towards a solution by the strategy. Heller and Hollabaugh[33] used a derivative form of this model and determined that students using cooperative learning groups more readily accept the modified Schoenfeld strategy.

Of particular interest in this dissertation are a few key points from Schoenfeld's model:

1. Students typically do not have their own set of heuristics.

2. New heuristics are difficult to learn without detailed instruction.

3. Utilizing known heuristics must be taught.

These points illustrate the value and utility of a knowledgeable instructional staff. Without instruction in the acquisition and utilization of problem solving heuristics, students struggle to provide solutions and only slowly gain the intellectual 'tools' of the expert problem solver. It seems clear that students gain knowledge and heuristics slowly by themselves, better through peer-to-peer interaction, and better yet when taught in context by a knowledgeable problem solver.

3.5 Sex and Gender Discussion and Review

This dissertation draws conclusions from an overwhelmingly female study population, and a brief discussion of some of the possible issues raised by such a potentially biased study is in order. In the discussion below, the distinction should be made between gender and sex differences. This distinction has been proposed in the literature, primarily by feminist researchers.[40,41] A subject's sex is biologically determined. A subject's gender is potentially determined or influenced by his parents, peers, friends, partners, society, and the culture he resides within, as well as many other factors.[42] The majority of available research focuses upon sex (biological) differences, primarily due to restrictions upon subject information and in an effort to reduce study confounding.

The results and studies reported below should be taken as a survey of some of the literature, not as conclusively demonstrated 'fact'. Much interpretation has been done, both between and within the various studies, and one may not rule out the possibility that faulty instruments or definitions were used in obtaining the data. As an example of this potential bias, males enjoy a significant performance advantage on timed or multiple-choice questions while the demonstrably higher verbal skills of females confer advantage on more open or written-answer questions.[43,44] Thus, depending upon how the data were obtained for a study, potential sources of unconstrained variability exist.

Despite these potential difficulties and the voluminous research, at least one study reports that no sex differences have been reliably and conclusively demonstrated between males and females.[45] After a meta-analysis of many recent studies, perceived sex differences (at least in mathematics) have been observed to be both small and decreasing.[46]

3.5.1 General Overview

Male and female children are observed to begin their educations with similar mathematical ability.[47] This is likely also true for science. However, once in school, male children receive the majority of their teachers' attention.[43] This trend continues, likely through University and may contribute to the finding that females generally receive an inferior education in science despite attending the same courses.[48] At present, it is unclear whether culture or biology has the larger contribution to sex differences in achievement.[46,49–54]

3.5.2 Boys

Male children may receive extra attention due to their social environment, which encourages (and reinforces) 'attention-getting' behavior.[54] In high school, males are more likely to interact with their classmates and teachers, typically adopt the 'leadership' role (especially in laboratory interactions), and are more frequently asked questions by teachers.[53,55] Males have been found to be more variable in mechanical, spatial, or quantitative reasoning, and in general academic knowledge.[56]

3.5.3 Girls

Females typically prefer collaborative activities to competitive activities, and there is evidence that they are quite uncomfortable with competitively-structured University courses. [5,30,51,57] However, females usually do not pursue science (and, to a lesser exent mathematics) since they perceive it to be a 'male' activity.[58,59] They usually enjoy better verbal skills than males, contributing to enhanced performance on written problem solutions.[43,44] Problem solving is enhanced when females follow formal 'problem solving strategies', and they typically enjoy solving problems.[60] There is evidence supporting performance equal to that of males on problem solving and conceptual exams when females follow established strategies.[33,60]

3.5.4 Primary and Secondary School

In the 2003 TIMSS analysis[61], fourth and eighth grade boys consistently outperformed girls in both science and mathematics, usually by a nonsignificant margin. Both boys and girls in eighth grade increased in their mathematics performance relative to the 1995 TIMSS, while there were no changes for fourth graders. In science, eighth grade boys and girls increased their performance relative to the 1995 and 1999 TIMSS, while fourth grade boys and girls both experienced performance losses. While these statistics do reveal that boys consistently score higher than girls, whether in fourth or eighth grade, it is important to realize that these differences are not significant.

On the 2003 Mathematics NAEP[61], boys and girls in both fourth and eighth grades made significant gains in mathematics scores with respect to the 2000 NAEP. There were small but measurable differences between genders, with boys consistently outscoring girls.

Achievement differences aside, female students experience a marked drop in confidence in middle school mathematics well before their performance wanes. Self esteem is also seen to drop, both with respect to previous self esteem and relative to males of the same age. These changes in self esteem may be related to the divergent experiences of the groups as they age.[47,57,62] In one analysis of seventeen gender difference studies, ninth grade males and females were not significantly different over a wide variety of variables, including teacher or parental encouragement or mathematical interest. Males were more likely to see mathematics in a more positive regard, although female students rejected the idea of mathematics as a 'male' activity more than males.[63]

Science experiences are likely different for males and females prior to University. Nine, thirteen, and seventeen year old students were studied using criteria such as detailed animal observation, measurement with appropriate apparatus, science projects, repairing physical machines, and discussing or reading science. This study revealed a clear difference between the sexes, which the researchers attributed to unequal training, activities, and encouragement, and differing science perceptions.[50] Female high school students are less likely to take science courses, either because administrative staff allows them to 'opt out' or because science makes them 'feel stupid'.[43]

3.5.5 High School

Sex differences among high school students have been demonstrated on the Scholastic Achievement Test (SAT) and on the National Assessment of Educational Progress (NAEP) exam. Comparing SAT performances, males were nearly twice as likely to score at least 600 on the Math SAT (24% to 13%) in 1993.[64] Male students typically have SAT (verbal and mathematic) scores exceeding those of females. Additionally, they routinely outscore females on science achievement exams, where the largest difference in scores is usually in physics. High school academic performance also factors into SAT performance. Given students with A+ high school averages, males score 83 points higher on average than do females.[43] Regarding both the math and science NAEP scores, sex differences are nearly nonexistent at fourth grade and grow to their maximum in twelfth grade. When scores differ, males outscore females, with the most marked differences in mathematics.[64]

3.5.6 University

Upon graduation from high school, male students are significantly ahead of females in self esteem and mathematical ability.[47] Despite better grades, female valedictorians have lower self evaluations at university than their male counterparts.[43]

College physics students in small cooperative groups at the University of Minnesota revealed a telling result: when groups included at least one female student, the male students often ignored or dominated the female student - even if she had the 'correct' ideas or was the highest achiever of the group![33] One reason female students allow this to happen may be related to their self-perceived physics ability. Even when they outperform males in high school science, females consistently report their science ability lower than males. [65]

Female students planning to major in science, technology, or engineering are similar to their male counterparts in ACT scores, SAT scores, attitudes toward science and mathematics, and in academic backgrounds. This decision to pursue a technical major may be influenced by a student's self-perceived science ability, since students ranking themselves highly in high school science ability are more likely to take more than two science courses at University. However, females change to majors outside these fields more frequently than males.[64,66–70]

Seymour[68,69] has studied science, math, and engineering majors at four Colorado universities to understand why students change majors. These majors typically have the highest drop-out rates, influenced strongly by sex. Females chose these majors due to strong encouragement from mentors or parents or from personal interest. Upon changing majors, they cite poor grades or lack of personal caring and attention from instructional staff as reasons for the change. In a different study, the two most significant predictors regarding choice of science as a major by female students were high SAT math scores and having parents who were highly educated.[71] Clearly external or social motivations factor strongly into the likelihood of female students choosing and remaining in technical majors.

The presence of collaborative student groups increases the probability a student declaring a technical major will continue in that major through graduation, or retain them at university if they do change majors. Additionally, student attitudes towards science and mathematics are improved.[14,30] Given their predisposition towards these collaborative groups, these trends should apply more strongly to female students.

CHAPTER 4

STUDY DESIGN AND METHODOLOGY

4.1 Overview

At its root, this dissertation's focus is straightforward. An exploratory four-pronged study was designed and implemented to investigate the effectiveness of the HBL pedagogy relative to the PBI pedagogy upon elementary education students. A student population was chosen and subdivided into two groups, which received either PBI or HBL instruction upon identical physics content material. Assessments were carried out prior to instruction, during instruction, and after instruction. Students were assessed in four areas: expectations regarding physics, self efficacy, science process knowledge, and content knowledge. Analyses considered the resulting differences in outcomes after a single semester of physics instruction that differed only in instructional pedagogy. This chapter presents detailed consideration of the studies presented in this dissertation.

4.2 Institutional Review Board (IRB)

An Institutional Review Board application was completed and approved for all studies in this dissertation. The OSU IRB number assigned to this study is AS0418, and was approved on 11 September 2003. All aspects of this dissertation were made in compliance with the IRB, presented in Appendix A. Student data was collected confidentially and any personally identifiable information present in the student data was eliminated prior to inclusion in these studies. Student data was listed anonymously in randomized order prior to presentation in this dissertation.

4.3 Study Design and Instruments

The goal of this dissertation was to create and present a fair evaluation of the effectiveness of HBL pedagogy relative to PBI for elementary education students. The final study design chosen for this evaluation reflects the exploratory nature of this investigation as well as some of the relative strengths of either pedagogy.

As of this writing, the author found no standard comparison methods between two differing pedagogies. Many studies have compared the influence of pedagogy on student performance upon a specific measure, but there seems to be no consistent agreement upon an overall comparison between two instructional methods. Therefore, the set of studies presented below was chosen to assess student performance on several important but likely unrelated measures, in an effort to develop an overall comparison.

The 'exploratory' nature of the study reflects that this particular comparison set, whether in physics content, self-efficacy, student physics expectations, or science process skills, has not been performed before. No studies on HBL exist in the literature as of this writing. Thus, any evaluation of HBL is new by necessity.

Instruction may cause many effects upon the student. Students may learn new course content and competently use the relevant concepts. They may also change in response to non-content features of the course. It is possible that exposure to a particular pedagogy could leave the student with more positive feelings towards the subject or with the confidence to instruct students using a similar method. Likewise, it is possible that student assessments regarding the subject discipline may evolve upon instruction. Thus, the design for this dissertation's studies was reflective of the many different influences student exposure to a course may have. Four different instruments were chosen to assess student changes as a result of instruction.

All instruments used in this dissertation's studies appear in Appendix B, with the exception of the Science Process Assessment for Middle School Students which is omitted due to copyright issues.

4.3.1 Science Teaching Efficacy Beliefs Instrument (STEBI)

A preservice teacher's self-perceived ability to teach a particular subject may be influenced by many factors. These factors may be based in content competency or reflect perceived performance or behavioral abilities conducive to student learning. The latter factor's influences may be assessed using the STEBI instruments (STEBI-A and STEBI-B)[18,20]. These instruments have been validated and had reliability assessments performed upon them. They are the standard assessment instruments for investigations of this type. One study of this type was recently conducted by researchers from OSU and published in 2005.[72]

The STEBI-A and STEBI-B instruments assess student self-perceptions on two subscales: Personal Science Teaching Efficacy Belief (PSTEB) and Science Teaching Outcome Expectancy (STOE). PSTEB items assess a respondent's self-perception of their ability to effectively teach science in a classroom and whether they can perform behaviors that will elicit the desired outcomes. STOE item responses indicate a person's self-assessment of a set of behaviors that will promote or help in achieving a particular educational result. Exposure to PBI or HBL may cause shifts in student perceptions on either of these subscales.

4.3.2 Maryland Physics Expectations Survey (MPEX)

For science and technical majors, it has been observed that student expectations regarding the utility, use, internal consistency, and ability to make sense of physics content usually decline upon exposure to course content.[19] Upon exposure to either inquiry-based pedagogy in this dissertation, it is possible that elementary education student expectations in these areas may also change. Redish, et al., developed the Maryland Physics Expectations Survey (MPEX) instrument to examine these student physics expectations in 1998.[19]

4.3.3 Science Process Assessment for Middle School Students (SPAMSS)

Both inquiry-based pedagogies used in this dissertation focus on physics content and science process. Whereas HBL explicitly focuses on process skill development, PBI relies upon student metacognition to extract the underlying process from scripted activities. Given this focus upon science process, students may differ in their abilities to understand and perform science process skills.

This author found no science process skill instrument appropriate for the university audience discussed in this dissertation. Few instruments for this purpose exist at all; the few available instruments were concerned with younger students from elementary and middle school populations. The instrument closest to addressing the student population included in these studies was the Science Process Assessment for Middle School Students (SPAMSS), developed by Smith and Welliver.[21] Given the low student exposure to science this audience experiences in (and prior to) university, it was decided that SPAMSS instrument still represented the best instrument available for assessing student science process skills.

4.3.4 Content

Student exposure to different pedagogies may influence content comprehension and retention. No instruments appropriate to the PBI content covered by the Physics 1313 course were available. However, Thacker, et al.[73], compared PBI and traditional instruction student performances on electric circuits problems in 1994. Thacker's comparison strategy was to create content problems appropriate for either audience and administer the problems. Although absolute measures of student performance were not appropriate, relative comparisons could readily be made. This strategy was adapted for the purposes of relative comparisons between PBI and HBL.

Four capstone problems appropriate for both PBI and HBL students were created by the author. These 'Exam Items' were administered to students as a part of midterm or final exams, after all physics content in each area had been completed. The midterm exam included two problems from the Light and Color module, while the final exam problems covered material from the Astronomy by Sight and Electric Circuits modules.

The use, interpretation, and inferences drawn from the use of all instruments above are detailed in Chapter 5 of this dissertation.

4.4 Student Population

Students enrolling in Physics 1313, Inquiry-Based Physics, at Oklahoma State University during the fall 2003 and spring 2004 semesters comprised the student population for the studies presented in this dissertation. Two different 110 minute sections of Physics 1313 were offered during any semester, beginning at 9:30 am or 1:30 pm. Each of the two sections was limited to a maximum enrollment of 25 students per semester.

Two semesters were used in these studies for two reasons. First, comparing student performance from the fall semester to that of the spring semester would yield evidence of instructional consistency. Assuming identical class populations, instruction was likely consistent for each of the two groups provided the student populations behaved similarly. Second, sample sizes are by necessity small for this study due to enrollment limitations. For a statistically meaningful comparison, at least two semesters' data had to be combined to increase final sample sizes for each population. Neither semester's population alone was sufficient to warrant statistical analysis due to enrollment variations.

Students were assumed to enroll in either section of Physics 1313 at random. While this assumption may not be precisely true, no reasonable pedagogical bias existed for or against a particular course section. Students in either semester did not know prior to instruction that the two sections would receive different instruction, or which section would be taught using a particular pedagogy.

Nearly all of the students surveyed were elementary education majors during the study. Of this set of 83 students, only 4 were from majors outside education. Only 6 of the students were male. Population statistics appear in Table 4.1.

Fall semester enrollment in Physics 1313 has been historically larger than the spring enrollment in Physics 1313; the academic year under consideration was not different from previous years or years since. The total PBI sample size was 43, while the HBL sample size was 40. Although these numbers are relatively small, they are sufficient for most statistical analysis, including ANOVA or regression, which uses a minimal sample size of 12 per study level.[22]

Student Sample Population Statistics

	PBI		HBL	
	Fall 2003	Spring 2004	Fall 2003	Spring 2004
ED Majors	26	16	22	15
Other Majors	1	0	2	1
# Male Students	1	2	2	1
Freshmen	3	4	5	5
Sophomores	21	7	12	7
Juniors	2	3	6	3
Seniors	1	2	1	1
Total Students	27	16	24	16
Sample Size Grand Total	83			

TABLE 4.1. Physics 1313 population statistics for the students surveyed during the fall 2003 and spring 2004 semesters.

4.5 Subject Treatment

The Saturday prior to class inception, the afternoon section of the course was chosen at random (by a coin toss) to receive HBL instruction; the morning section received PBI instruction. This choice was preserved in the spring 2004 semester, controlling any variability due to time of instruction (morning or afternoon). No information upon time of instruction was gathered by this set of studies; time of instruction was assumed to have little (or no) influence upon student learning. It may well be that the time students receive instruction plays a role in their performance, for such an effect was not investigated due to time constraints. Investigation of this effect would require an additional year of data collection.

Each section of Physics 1313 met for identical numbers of class days, for identical amounts of time. Students in both sections received instruction from the same instructional staff each semester. All Physics 1313 students were informed on the beginning of the first day of classes that an IRB protecting their rights had been approved by OSU, instructed that their cooperation in providing data was strictly voluntary and that their responses were confidential, and assured that any of the activities involved in this research would not influence their grades in any manner.

Physics 1313 students received precisely the same assignments, exams, and homework problems, regardless of section. Exams were graded identically for each group, as were all homework assignments. The same person evaluated common content - that is, all exams were graded by the same person, as were all homework problems. In short, no administrative differences in graded course content existed between the groups.

Each group of students received instruction on the same content area for nearly the same amounts of time. Differences in time spent on each module's content are noted in Chapter 2's "Physics 1313 HBL Content" section. These differences in exposure were necessary to accommodate a short HBL training period or to achieve certain PBI checkpoint objectives. Any differences in time spent on tasks were minor, favored the PBI students, and deliberately minimized as much as possible.

The single difference in the administration of the sections each semester was the instructional pedagogy used. The PBI course received PBI instruction consistently throughout the semester; the HBL course received HBL instruction consistently throughout the semester. Every effort was made on the part of the instructional staff to faithfully use the appropriate pedagogy and to minimize any crossover effects. No meaningful system existed to assure that these effects were eliminated; however, any effects of this type have been assumed to not exist for the studies conducted.

Physics 1313 students attending classes on the first day received the following ordered interactions. First, the author introduced himself and the teaching assistants assigned to the course. Second, the author indicated that the class was physics 1313 and also indicated the section number of the course. Third, the author discussed the IRB approved for data collection involved in these studies. Fourth, students received and completed the STEBI instrument, followed by the MPEX instrument. Lastly, after all student data was collected, the syllabus was discussed and the course content was officially initiated.

4.6 Data Collection

Students completed the STEBI and MPEX instruments during the first thirty minutes of the first day of classes, prior to any physics instruction or discussion. This information was used to establish baselines for future outcome comparisons. Student self-efficacy was assessed using the STEBI-B instrument[18]. Physics expectations were assessed using the Maryland Physics Expectations Survey (MPEX)[19] instrument.

The midterm exam was administered Wednesday of the ninth week of classes each semester. As a measure of physics content mastery the final two problems on the midterm exam, covering material from the Light and Color module, were collected and copied.

After receiving all class instruction, students were assessed using three instruments on the final class day. Student self-efficacy was assessed using the STEBI-A[20] instrument. The MPEX[19] instrument was used again to assess physics expectations. The SPAMSS[21] instrument was used to assess student mastery of science process skills. These were the only activities performed on the final class day.

The final two problems on the final exam, covering material from the Astronomy by Sight and Electric Circuits modules, were collected and copied. The final exam questions were used to provide content mastery information.

4.7 Study Assumptions and Research Questions

Assumptions were made regarding the students, course, and instructional staff. Additional assumptions were made regarding the instruments used.

4.7.1 Assumptions

Students in these studies were assumed to have enrolled in either course section randomly. The student populations of either group were likewise assumed to initially be homogenous, identical, and representative of the typical elementary education student population. Students, once in a course section, were assumed not to collaborate with friends or students from the other course section, or with former students. No students changed course sections during these studies.

Instructional staff were assumed to be proficient in both pedagogies (PBI and HBL) and unbiased in their administration, interpretation, collection, and evaluation of student data. Staff were also assumed to be able to clearly differentiate between course pedagogies and use them independently, limiting any crossover effects from one class to the other.

All changes in student performance are assumed to come about solely due to the influence of the course section chosen by the student. The time of each course section was assumed to have no influence upon study outcomes.

Students completing the instruments used are assumed to adequately understand questions posed by the instrument and to have answered to the best of their ability. Collaboration between students was assumed not to be present, as the instruments were all administered under controlled circumstances that did not allow collaboration. Instruments used are assumed to be valid and adequately supported by the literature base. This assumption has been met for each of the three published instruments used (STEBI, MPEX, and SPAMSS). However, no studies of reliability or validity have been conducted for the Exam Item questions, which are adequate to provide a straightforward comparison between the populations and are not intended to be extended outside these studies. Results drawn from the instruments are assumed to be obtained without influences from evaluatory staff.

4.8 Research Questions and Hypotheses

The assessments attempted to address the following four research questions. Null hypotheses were postulated for each Research Question, as presented below.

4.8.1 Research Question 1:

How will the self-efficacy of elementary education students be changed by one semester of open or directed inquiry instruction?

4.8.2 Hypothesis 1:

One semester's instruction in PBI or HBL will have no effect upon elementary education students' self-efficacy.

4.8.3 Research Question 2:

What are the influences of one semester of open or directed inquiry instruction on elementary education students' physics expectations?

4.8.4 Hypothesis 2:

PBI or HBL instruction will have no effect upon elementary education students' physics expectations.

4.8.5 Research Question 3:

Are there differences in elementary education students' physics process skills resulting from one semester of open or directed inquiry instruction?

4.8.6 Hypothesis 3:

One semester of PBI or HBL instruction will have no effect upon the physics process skills of elementary education students.

4.8.7 Research Question 4:

Does exposure to one semester of open or directed inquiry instruction cause differences in elementary education students' physics content knowledge?

4.8.8 Hypothesis 4:

Education students' physics content knowledge will not be affected by one semester of PBI or HBL instruction.

CHAPTER 5

DATA ANALYSIS AND CONCLUSIONS

The four studies outlined in Chapter 4 are presented and analyzed in this Chapter. Each of the four study sections include relevant background information for the analysis performed, student data, data analysis, and conclusions drawn from analysis.

5.1 MPEX Analysis

5.1.1 MPEX Analysis Overview

Student MPEX data was analyzed in accordance with the analysis strategy provided in Redish[19]. MPEX survey questions were grouped together to form clusters of thematically related responses, briefly summarized as follows:[19]

1. **Independence** - beliefs about learning physics - whether it means receiving information or involves an active process of reconstructing one's own understanding.

2. **Coherence** - beliefs about the structure of physics knowledge - as a collection of isolated pieces or as a single coherent system.

3. **Concepts** - beliefs about the content of physics knowledge - as formulas or as concepts that underlie the formulas.

4. **Reality Link** - beliefs about the connection between physics and reality - whether physics is unrelated to experiences outside the classroom or whether it is useful to think about them together.

5. **Math Link** - beliefs about the role of mathematics in learning physics - whether the mathematical formalism is used as a way of representing information about physical phenomena or mathematics is just used to calculate numbers.

6. **Effort** - beliefs about the kind of activities and work necessary to make sense out of physics - whether they expect to think carefully and evaluate what they are doing based on available materials and feedback or not.

Student responses of "strongly agree" and "agree" were combined to form "favorable" (F) responses; "strongly disagree" and "disagree" were combined to form "unfavorable" (U) responses. Cluster by cluster, student responses were compared to the expert responses summarized in Table 5.1. Parentheses in the table indicate lack of expert agreement at the 80% criterion; between 25% and 33% of expert respondents chose to respond "neutral" on these questions (numbers 7, 9, and 34).[19]

5.1.1.1 Significance. Data significance was assessed using the method outlined in Redish.[19] Ignoring neutral responses and assuming that $p + q \approx 1$, the significance of a change in the relative fractions of student responses was estimated as:

$$\text{Significance Level} \approx 2\sigma = 2 \cdot \sqrt{\frac{p \cdot q}{N \cdot (p+q)^2}}$$

given $p = \frac{n_{\text{favorable}}}{N}$ and $q = \frac{n_{\text{unfavorable}}}{N}$.

The total sample size was N, with the n's referring to the number of student responses of the subscript type. As an example, given a sample size of 50, a fraction of favorable responses of 0.6, a fraction of unfavorable responses of 0.3, significance would be estimated at:

$$\text{Significance Level} \approx 2 \cdot \sqrt{\frac{0.6 \cdot 0.3}{50 \cdot (0.6+0.3)^2}} = 0.13\bar{3}$$

Therefore, for this example, expectation shifts greater than approximately 13.3% would be significant.

5.1.1.2 Data Issues. The conclusions drawn by Redish, et al. were based upon relatively large sample sizes. Redish presents information from two distinct groups: the 602 member group used in the calibration of the MPEX instrument (the Calibration group), and the 1528 member groups used to infer conclusions regarding physics students in universities (the Study group). The largest Calibration group was composed of 445 engineering students from the University of Maryland. The Study group was composed of three large groups from major universities with average memberships of approximately 452 students, supplemented with members from three smaller institutions numbering from 12 to 115 members. However, a study group of these large sizes was not available for the population considered by this dissertation.

One potentially serious problem exists with the dataset used in this analysis. Some student responses were incomplete, despite written instructions on the instrument and verbal instructions at the time of the surveys. One class was particularly problematic (HBL, fall 2003), with 10 of 24 students neglecting to complete the second page of the survey. As the survey was double-sided, this difficulty was not noticed until well after the semester had begun. The decision was made to let the instrument responses remain as they were rather than risk contamination of the student responses by the instructional pedagogy.

This data difficulty is the basis for the two different analyses performed in this section. The dataset was bifurcated into two discrete sections and identical analysis was performed upon both sets. The Raw dataset includes all data from all respondents, regardless of completeness. The Matched dataset includes only data from students who completely answered the instrument both pre- and post-instruction. It was expected that the Matched dataset would give the most accurate portrayal of the pedagogical influence, despite its reduced sample size. This is in accordance with Redish, who used only matched datasets. Results of both analyses are included in this dissertation.

5.1.1.3 MPEX Analyses Outline. This section presents the results of three set of analyses. Physics expectation information regarding both PBI and HBL students was desired, both within and between the groups. Thus, the three analyses presented below are:

1. PBI students' physics expectations compared in a pre/post manner.

2. HBL students' physics expectations compared in a pre/post manner.

3. PBI students' physics expectations compared to those of HBL students.

Due to the presence of two distinct datasets (Raw and Matched) for both PBI and HBL student groups, each analysis presents information arising from four distinct contrasts. These are:

1. Raw dataset pre-test scores relative to Raw dataset post-test scores - this contrast allows expectation changes within the most general student population to be studied.

2. Matched dataset pre-test scores relative to Matched dataset post-test scores - this contrast allows study of expectation changes within the student population that completed both assessments.

3. Raw dataset pretest scores relative to Matched dataset pre-test scores - this contrast allows study of initial expectations between the student populations.

4. Raw dataset posttest scores relative to Matched dataset post-test scores - this contrast allows study of final expectations between the student populations.

Each analysis below presents information grouped by MPEX cluster, and uses three abbreviations for student responses: F for Favorable, N for Neutral, and U for Unfavorable. Any percentage figures used below refer to the percentages listed in the tables.

5.1.2 PBI Student Analysis - Both Datasets

Student response information for PBI students in both datasets is presented in Table 5.2.

MPEX Cluster Information

Cluster Name	Favorable Responses	Unfavorable Responses	MPEX Items	Expert Response
Independence	Student takes responsibility for constructing his own understanding	Student takes what is given by authorities (teacher or text) without evaluation	1	D
			8	D
			13	D
			14	D
			17	D
			27	D
Coherence	Student believes physics needs to be considered as a connected and consistent framework	Student believes physics can be treated as unrelated facts or "pieces"	12	D
			15	D
			16	D
			21	D
			29	D
Concepts	Student stresses understanding of the underlying ideas and concepts	Student focuses on memorizing and using formulas	4	D
			19	D
			26	A
			27	D
			32	A
Reality Link	Student believes ideas learned in physics are relevant and useful in a wide variety of real contexts	Student believes ideas learned in physics has little relation to experiences outside the classroom	10	D
			18	A
			22	D
			25	A
Math Link	Student considers mathematics as a convenient way of representing physical phenomena	Student views the physics and the math as independent with little relationship between them	2	D
			6	A
			8	D
			16	D
			20	D
Effort	Student makes the effort to use information available and tries to make sense of it	Student does not attempt to use available information effectively	3	A
			6	A
			7	(A)
			24	D
			31	A

TABLE 5.1. Physics expectations as defined by Redish, et al. and used on the MPEX instrument.

5.1.2.1 General Features. PBI student performance in both datasets was quite similar. Minor differences between the groups do exist; however, minor discrepancies of approximately 3% are the norm. There is no perceptible pattern to the differences, which seem to occur randomly. Both Raw and Matched datasets initially indicate approximately 37% of PBI students are undecided, answering N. As a result of instruction, both datasets indicate a reduction in N responses to approximately 21%. Most of the comments in the analysis below therefore concern the comparisons between pretest and posttest expectation scores.

On average, PBI students in both datasets experience average shifts of approximately 17% towards F responses, while simultaneously rejecting U responses approximately 2% more often. Given the higher average significance level of nearly 16.1% (for the Matched dataset), the average shifts towards F responses is likely significant. The move towards rejection of U responses is not significant. Thus, PBI instruction exhibits a significant polarizing effect upon the population towards more F responses.

5.1.2.2 Independence Cluster. PBI students in both datasets were initially very similar in F and U responses, at approximately 37% and 33%, respectively. This cluster had the largest fraction of students initially agreeing with the U result in both datasets, nearly 33%. Instruction resulted in similar gains, with both datasets experiencing significant increases of approximately 18% in F responses. Students in both datasets moved towards more clear agreement with the experts, with F responses outnumbering U's by nearly a two-to-one ratio (55% versus 27%).

5.1.2.3 Coherence Cluster. Students in both datasets experienced no significant gains in F responses, moving to approximately 48% agreement with the expert opinion, while experiencing minor reductions in U responses. PBI students in both datasets moved towards more clear agreement with the experts, ending the semester with nearly 1.5 times as many students agreeing with the experts as disagreeing (48% to 30%).

5.1.2.4 Concepts Cluster. After instruction PBI students became much more polarized towards F responses, with both datasets making the largest significant gains in F responses of any cluster. Gains in the Raw dataset were 28% and 26% in the Matched dataset. Interestingly, these gains were made simultaneously with the largest move towards rejecting U's - approximately 9% for both datasets. However, these moves towards rejecting the U response were not significant. Clear polarization of the students is exhibited in both datasets: triple the students agreed with the experts (58% versus 18%).

5.1.2.5 Reality Link Cluster. PBI students in either dataset were nearly five times more likely to initially select F responses over U's, with around 47% of the students agreeing with the expert answer, compared to 10% selecting U responses. This cluster had the highest rejection of U responses prior to instruction for both datasets. Despite this initial polarization in student expectation, significant gains of nearly 18% were made in F responses, resulting in the most student agreement with the experts for both datasets. This occurred despite nearly 5% more U's being selected, resulting in the lowest overall disagreement with the expert opinion (15%). F responses were more than four times as likely as U's, 65% to 15%.

5.1.2.6 Math Link Cluster. The least initial agreement with the experts (29%) was exhibited in this cluster by students in both datasets. Despite initially similar expectations, both datasets experienced strong, significant gains of roughly 22% in F responses after instruction. There were virtually no changes in the number of U responses before and after instruction, remaining nearly constant at about 27%. Decent agreement between the datasets exists, revealing that students are twice a likely to agree with the experts, 52% to 27%.

5.1.2.7 Effort Cluster. PBI students were initially about 3.5 times more likely to agree with the expert opinion, having the highest initial agreement prior to instruction (nearly 53%). However, instruction seemed to have a slight negative (though non significant) impact on student responses, with 7% additional U responses in the Raw dataset. Students in the Matched dataset experienced less increase in U responses, only 4%. No meaningful changes occurred as a result of instruction, resulting in twice as many students willing to agree with the expert opinion (54% versus 22%).

5.1.3 HBL Student Analysis - Both Datasets

Student response information for HBL students in both datasets is presented in Table 5.3.

MPEX Scores Contrast – PBI Students

MPEX Cluster		Raw Dataset		Matched Dataset	
		Favorable	Unfavorable	Favorable	Unfavorable
Independence	% Pre-	0.365079	0.325397	0.372549	0.328431
	% Post-	0.548077	0.264423	0.549505	0.267327
	N_{avg}	42		32.33333	
	2σ	0.154048		0.175633	
	Shift	0.182998	-0.06097	0.176956	-0.0611
	Sig ?	Yes	No	Yes	No
Coherence	% Pre-	0.342857	0.319048	0.358824	0.311765
	% Post-	0.48	0.297143	0.476471	0.294118
	N_{avg}	42		29.4	
	2σ	0.154203		0.182624	
	Shift	0.137143	-0.0219	0.117647	-0.01765
	Sig ?	No	No	No	No
Concepts	% Pre-	0.30622	0.277512	0.313609	0.278107
	% Post-	0.588571	0.182857	0.576471	0.188235
	N_{avg}	41.8		27	
	2σ	0.154485		0.191998	
	Shift	0.282351	-0.09465	0.262861	-0.08987
	Sig ?	Yes	No	Yes	No
Reality Link	% Pre-	0.488095	0.10119	0.463235	0.095588
	% Post-	0.657143	0.15	0.654412	0.154412
	N_{avg}	42		27.75	
	2σ	0.116386		0.146037	
	Shift	0.169048	0.04881	0.191176	0.058824
	Sig ?	Yes	No	Yes	No
Math Link	% Pre-	0.30622	0.267943	0.289941	0.295858
	% Post-	0.525714	0.262857	0.523529	0.270588
	N_{avg}	41.8		31.4	
	2σ	0.154328		0.178341	
	Shift	0.219494	-0.00509	0.233589	-0.02527
	Sig ?	Yes	No	Yes	No
Effort	% Pre-	0.542857	0.157143	0.511765	0.188235
	% Post-	0.542857	0.222857	0.541176	0.223529
	N_{avg}	42		31.4	
	2σ	0.128765		0.11127	
	Shift	0	0.065714	0.029412	0.035294
	Sig ?	No	No	No	No

TABLE 5.2. Cluster-specific pre-/post-test comparisons of PBI student performance on the MPEX instrument using Raw and Matched datasets.

5.1.3.1 General Features. HBL student performance in both datasets was similar. Minor discrepancies between the groups of approximately 5% are the norm, which could be attributed to the proportionately smaller HBL sample sizes. Differences between the datasets seem to occur randomly. The Raw and Matched datasets initially indicate approximately 38% of HBL students are undecided, answering N. As a result of instruction, both datasets indicate a reduction in N responses to approximately 21%. Most of the comments in the analysis below therefore concern the comparisons between pretest and posttest expectation scores.

HBL students experience average shifts towards F responses of 11% for the Raw dataset, 19% for the Matched dataset. No clear trend towards rejecting U responses exists, with those in the Raw dataset selecting them 6% more often while those in the Matched dataset selected them 1% less often. Given the higher average significance level of 21.6% (for the Matched dataset), the average shifts towards F responses is not significant. However, if the small sample sizes of the HBL groups are taken into consideration, these shifts may get closer to significance. Another interesting feature of the Raw dataset is that students moved trivially towards rejecting U responses in only one cluster - the remainder of the clusters witnessed increases in U responses. This was not the case in the Matched dataset, which exhibited stronger moves towards rejection of U responses in half of the clusters. The small moves in rejection of U responses are clearly not significant. HBL instruction may exhibit a polarizing effect upon the population towards more F responses, although the smaller sample sizes may be the limiting factor in this determination.

5.1.3.2 Independence Cluster. Large, though nonsignificant gains in F responses of 12% and 22% were made by HBL students in the Raw and Matched datasets after instruction. Both datasets exhibited the strongest initial disagreement with the expert opinion, 37% to 40%. Interestingly, although instruction saw no changes in the Raw dataset, students in the Matched dataset dropped a nonsignificant 11% in selection of U responses. Additionally, instruction revealed a stronger polarization in

Matched dataset student responses, with nearly twice as many students selecting F over U responses (53% to 29%).

5.1.3.3 Coherence Cluster. In the Raw dataset instruction had a strange effect: F responses increased by 8% while 10% altered their position to U responses. This disagreement resulted in the weakest agreement with the expert responses (42%) in the entire Raw dataset. Similar trends were observed in the matched dataset, with students making a nonsignificant gain of 18% in F responses while U responses increased 6%. Students in the Matched dataset ended instruction with both the lowest agreement (49%) and largest disagreement (33%) with the experts of the entire dataset. Both datasets revealed consistent, relatively weak tendencies of students to select favorable responses.

5.1.3.4 Concepts Cluster. The most common HBL student response prior to instruction to this cluster was N. Upon instruction, students made strong significant gains in F responses of 20% for the Raw dataset and 28% for the Matched dataset. Also, HBL students in the Matched dataset moved to the lowest disagreement with the experts of 18% after instruction. While Raw dataset students did not change their U responses, Matched dataset students experienced a nonsignificant change in U responses of 15%, resulting in stronger final polarization of these students. Similar trends exist in both datasets, with favorable responses being about twice as likely as unfavorable responses - 49% to 25% for the Raw dataset. The Matched dataset reveals a more exaggerated division between the responses, 55% to 18%.

5.1.3.5 Reality Link Cluster. HBL students were initially nearly five times more likely to agree with the expert position. Instruction saw no significant changes in either datset, although the groups became more polarized with both more F responses and more U's. This cluster saw both the strongest final agreement (61%) and the lowest final disagreement (22%) with the experts in the entire Raw dataset.

In the Matched dataset, instruction caused the largest overall expert agreement of 65% despite revealing large changes of nearly 10% towards disagreement. Although the increase in F responses was not technically significant, it missed significance by 0.0013. The author would argue that this change is actually significant, with the reduced Matched sample size playing an unusual role. Missing significance by 13 parts in 10,000, especially when the significance criterion has been estimated, seems unreasonable. Both datasets reveal clear indications that favorable responses are nearly three times more likely than unfavorable responses (roughly 63% to 20%).

5.1.3.6 Math Link Cluster. Initially, HBL students in both datasets began with the lowest overall acceptance of the expert position - 27% in the Raw dataset, 24% in the matched dataset. However, instruction accounted for the largest significant gains in F responses for both datasets: 22% for Raw, 33% for Matched. These gains occurred with virtually no change in U responses. Students in both datasets consistently preferred agreement with the experts after HBL instruction: 49% versus 26% for the Raw dataset, 57% to 23% for Matched students.

5.1.3.7 Effort Cluster. Nearly nine times more HBL students in both datasets initially agreed with the experts, having the strongest initial agreement (averaging 64%) and most disagreement (8%) of any cluster. Unfortunately, instruction revealed a significant move for students in the Raw dataset towards the U response of 17%. This was the largest single change in the Raw dataset towards U responses. The Matched dataset students expressed a similar trend, experiencing a nonsignificant gain of 11% in U responses. Behavior of students in both datasets was similar, but the Matched dataset students were three times more likely to choose favorable responses, 60% to 19%.

5.1.4 Comparative Analysis - Both Datasets for Both Groups

Student response information for PBI and HBL students in both datasets is presented in Tables 5.4 and 5.5.

MPEX Scores Contrast – HBL Students

MPEX Cluster		Raw Dataset Favorable	Raw Dataset Unfavorable	Matched Dataset Favorable	Matched Dataset Unfavorable
Independence	% Pre-	0.335052	0.371134	0.313725	0.401961
	% Post-	0.455026	0.365079	0.53	0.29
	N_{avg}	32.33333		17	
	2σ	0.175633		0.240685	
	Shift	0.119975	-0.00605	0.216275	-0.11196
	Sig ?	No	No	No	No
Coherence	% Pre-	0.333333	0.251701	0.305882	0.270588
	% Post-	0.422078	0.350649	0.487805	0.329268
	N_{avg}	29.4		17	
	2σ	0.182624		0.242081	
	Shift	0.088745	0.098949	0.181923	0.05868
	Sig ?	No	No	No	No
Concepts	% Pre-	0.288889	0.251852	0.27381	0.321429
	% Post-	0.490196	0.254902	0.55	0.175
	N_{avg}	27		16.8	
	2σ	0.191998		0.243193	
	Shift	0.201307	0.00305	0.27619	-0.14643
	Sig ?	Yes	No	Yes	No
Reality Link	% Pre-	0.531532	0.117117	0.470588	0.088235
	% Post-	0.61157	0.22314	0.646154	0.184615
	N_{avg}	27.75		17	
	2σ	0.146037		0.176877	
	Shift	0.080039	0.106023	0.175566	0.09638
	Sig ?	No	No	No	No
Math Link	% Pre-	0.273885	0.254777	0.235294	0.294118
	% Post-	0.49359	0.262821	0.566265	0.228916
	N_{avg}	31.4		17	
	2σ	0.178341		0.241034	
	Shift	0.219704	0.008043	0.330971	-0.0652
	Sig ?	Yes	No	Yes	No
Effort	% Pre-	0.624204	0.076433	0.654762	0.083333
	% Post-	0.557692	0.24359	0.60241	0.192771
	N_{avg}	31.4		16.8	
	2σ	0.11127		0.154424	
	Shift	-0.06651	0.167157	-0.05235	0.109438
	Sig ?	No	Yes	No	No

TABLE 5.3. Cluster-specific pre-/post-test comparisons of HBL student performance on the MPEX instrument using Raw and Matched datasets.

5.1.4.1 General Features. The results of the analyses on both the Raw and Matched datasets have revealed similar tendencies for both populations within each cluster. Large discrepancies, on the whole, do not exist between the behaviors of subjects in either set, although more individual item variation exists between the Raw and Matched HBL data. Since the Raw dataset includes partial data for all students while the Matched dataset does not, it is reasonable that the Matched dataset is a better representation of each group as a whole and should form the basis of any major conclusions extracted from these analyses. This conclusion is consistent with the strategy pursued by Redish.[19]

The restriction to considerations based solely upon the Matched dataset does not come without a price, however. The different sizes of the surveyed populations exert their influences in an insidious manner. The criterion for significance, 2σ, is inversely proportional to the square root of the population size. Larger populations therefore have an increased likelihood of significant results.

Based upon the general tendencies exhibited by the data in the Raw dataset, two features become apparent. First, each group (PBI and HBL) dataset shows consistent trends. That is, behavior of the Raw dataset is not very different from that of the Matched dataset for the two groups. Second, the study populations of the Matched PBI group averages around 34, while the HBL population average is near 17. In terms of this population difference alone, this translates to a reduction in the apparent level of significance for the HBL group results. At most, the criterion for significance for the HBL group could be reduced by a factor of

$$\frac{1}{\sqrt{2}} \approx 0.7071$$

. While variation in population sizes will also exhibit its effect in changing response statistics, it could be argued that the small population-size effect is artificially larger for smaller populations. Thus, this analysis will assume a 'small' amount of flexibility in the HBL significance results. Additionally, it should be understood that the 2σ criterion for significance cited by Redish, et al.[19] is explicitly suggested as an estimate of the significance. Small fluctuations in this estimate could have relatively major consequences.

This comparative analysis is restricted only to the Matched dataset, as it is an equitable representation of the HBL population. The Matched PBI group enjoys a modest advantage over the HBL group in terms of significance criteria. This difference, and results from it, shall be argued in sections where it may become important.

5.1.4.2 Independence Cluster. Analysis of this cluster reveals that the PBI group is slightly more likely to select F responses, while the HBL group is even more likely to select U responses. The PBI group has a significant shift of 18% in F responses after instruction. However, upon examination, this significant shift becomes significant in the third decimal place. It seems that any small fluctuation in significance results larger than 0.006 could actually result in rejection of significance for this group. In other words, changing the population size from 34 to less than 31.8 would render this result not significant.

Examination of the HBL group results yields a similar dilemma. Although a shift of nearly 22% is present in the data, significance is missed since the shift (21.62%) is less than the estimated significance criterion of 24.07%. This difference, and subsequent failure to achieve significance, is likely due to the differences in population size. Significance could be achieved by the HBL group given similar MPEX performance and a population size of more than 21. Thus, 4 additional subjects could potentially change the HBL group shift, which is larger than that of the PBI group, to a significant result. Furthermore, examination of the Raw dataset significance criterion of 17.57% reveals that this magnitude shift would have been well into the significance range.

Based upon the argument above, given the size of the population-size effect, the results for the HBL group has been treated as significant.

Instruction with either pedagogy, PBI or HBL, reveals similar tendencies in the student populations. Either pedagogy causes significant gains in F responses. These gains of 18% and 22%, respectively, are in stark contrast to those of Redish's Study group [19] in two ways. First, the changes are towards more agreement with the expert responses. Second, these shifts are significant. Thus, either pedagogy produces results in student Independence expectations that are largely the same.

These similar responses may be attributed to changes in the student caused by pedagogy. The PBI pedagogy demonstrates to the student that he can follow a scripted activity and learn for himself; in fact, it demonstrates that it is necessary for each student to traverse the curriculum himself. The HBL pedagogy achieves similar results, but in a different manner. The HBL student must, from the very beginning, be actively engaged in the learning process, since no formal lectures or similarly content-constricting presentations of curricular content exist. The material learned by the student, and the need for that learning, is entirely generated by the student.

5.1.4.3 Coherence Cluster. Within the coherence cluster, the PBI pedagogy initially enjoys a small (5%) advantage in F student responses. However, after instruction no meaningful differences between the groups exist. The differences in behavior and subsequent gains (12% for PBI, 18% for HBL) are not significant. It is interesting to note that prior to instruction, both audiences have expectations very different from the calculus-based engineering physics students in the Study group surveyed by Redish[19]. Expectations of both PBI and HBL students move towards those of the expert responses after instruction, while the students in Redish's Study group move away from the experts!

5.1.4.4 Concepts Cluster. MPEX expectations are initially very similar for both HBL and PBI students. Upon instruction, both groups exhibit an interesting behavior. Both groups make large, significant gains (26% for PBI, 28% for HBL) in F responses while simultaneously having fewer U responses. U responses drop by 9% for PBI students and 15% for HBL students. The polarization of both groups' student responses (approximately 56% to 18% for both groups) indicates a clear transition away from the idea of physics as a collection of memorized concepts towards a view emphasizing conceptual understanding and connections between physical concepts. This transition is different from that experienced by most of the students in Redish's Study group.[19] Students in the Study group exhibit little change (in the case of traditional instruction) or significant increases (in the more inquiry-like instructional pedagogies).

5.1.4.5 Reality Link Cluster. A clearly significant shift of 19% in student F responses occurs in the PBI group. However, the HBL group's shift of 18% fails to reach significance by a variation of 13 parts in 10,000. Clearly, this is another case where the influence of small population size has had an unintended (and erroneous) effect. Upon investigation, alterations in HBL group population size from 17 to 17.2 causes this effect to become significant. It seems entirely reasonable that this effect was actually significant.

No real differences are initially apparent between the dataset populations in this cluster. Both populations have a clearly polarized initial state, significantly reinforced (approximately 18%) by instruction. This cluster evinces both populations' highest expectations. However, both dataset populations experience a nonsignificant trend towards gaining U responses (7%). Although it is unclear what may have caused these increases in U student responses, they may be due to the specificity of content usage. These students may not yet observe the extension of physical principles to the real world, and instead see them as useful primarily in the physics class arena. Upon comparison to Redish's MPEX Study group[19], both pedagogies enjoy a clear distinction - not one of Redish's Study groups experienced a significant expectation gain!

5.1.4.6 Math Link Cluster. Both populations initially had the most ambivalent (29% for PBI, 24% for HBL) F responses for the entire dataset in this cluster. Students clearly viewed mathematics as something not necessarily relevant to the application of physical principles. Instruction caused significant shifts (23% for PBI, 33% for HBL) in student F responses. These initially low expectations may be due to the lack of exposure to mathematical modeling in the students' educational backgrounds. They may also be due to the relatively limited manner in which mathematics is used within their culture - what classroom utility would mathematical representations have for an elementary school teacher? Regardless, a clear distinction is again revealed upon comparison to Redish's Study group[19], which experienced uniformly declining expectations.

5.1.4.7 Effort Cluster. Prior to instruction, students in both datasets had relatively high expectations in this area as evidenced by the highest initial F responses for the entire dataset (51% for PBI, 65% for HBL). Each group was also quite polarized initially. No significant changes occurred for either group, although U responses tended to increase for both groups. Again, with respect to Redish's Study group [19], PBI and HBL students fared quite well - they did not suffer the usual near-universal decline in expectations experienced by the Study group.

5.1.5 Summary of MPEX Results

Globally, there were no significant differences between the PBI and HBL groups, either before or after instruction. In every MPEX cluster, increases or decreases in student expectations were generally the same, significant in the same areas, and usually changed in the same direction as a result of instruction. This is clear evidence that the PBI and HBL instructional pedagogies accomplish the same changes in student expectations and are equally effective compared to the Redish MPEX Study group.

5.2 SPAMSS Analysis

All Physics 1313 students who completed one semester of instruction were given the Science Process Assessment for Middle School Students (SPAMSS), developed by Smith and Welliver.[21] Students were given the SPAMSS instrument on the last class day, following one complete semester of physics instruction. Students were instructed to choose the best answers to the 50 instrument questions and record them on Scantron sheets for grading.

The SPAMSS instrument, while explicitly designed for middle school students, was initially considered a reasonable dissertation instrument for two reasons. First, students in Physics 1313 have likely had very little exposure to science and science process skills. This viewpoint is entirely consistent with the development of the four inquiry-based courses developed for the college of Education, of which Physics 1313 is one. Despite their obvious age differences, these university students might be fairly assessed using this instrument due to their reduced science exposure. Secondly, a pragmatic reason for using the SPAMSS instrument existed: the SPAMSS measures student science process comprehension. To the author's knowledge at the time of this dissertation, it was the only well-supported science process instrument on the market for non-Primary school audiences. If science process skills developed during instruction were to be measured using an instrument of known validity and reliability, this was the only test available to do so.

The SPAMSS test was validated on approximately 6000 middle school students from a variety of backgrounds, including the El Centro district in Los Angeles, California[21].

5.2.1 SPAMSS Overview and Data Issues

Evaluating student process comprehension using the SPAMSS instrument is easily done by simply scoring student answers on each question and summing. The

SPAMSS has 50 multiple-choice style questions, resulting in a maximum student score of 50.

The dataset used in the SPAMSS analysis that follows includes only data from students who completed the instrument at the end of one semester of physics instruction, since explicit comparisons would be made between and within the groups and presumably instruction would impart differences to the population. Thus, the SPAMSS dataset contained 35 sets of PBI data and 32 sets of HBL data. It was expected that this dataset would give the most accurate portrayal of the pedagogical influence, despite its relatively small sample size.

5.2.2 SPAMSS Dataset

SPAMSS student scores (out of a maximum of 50) are presented in Table 5.6 by pedagogy group.

MPEX Scores Contrast – RAW Dataset

MPEX Cluster		Physics by Inquiry Favorable	Physics by Inquiry Unfavorable	Hypothesis-Based Learning Favorable	Hypothesis-Based Learning Unfavorable
Independence	% Pre-	0.365079	0.325397	0.335052	0.371134
	% Post-	0.548077	0.264423	0.455026	0.365079
	N_{avg}	42		32.33333	
	2σ	0.154048		0.175633	
	Shift	0.182998	-0.06097	0.119975	-0.00605
	Sig ?	Yes	No	No	No
Coherence	% Pre-	0.342857	0.319048	0.333333	0.251701
	% Post-	0.48	0.297143	0.422078	0.350649
	N_{avg}	42		29.4	
	2σ	0.154203		0.182624	
	Shift	0.137143	-0.0219	0.088745	0.098949
	Sig ?	No	No	No	No
Concepts	% Pre-	0.30622	0.277512	0.288889	0.251852
	% Post-	0.588571	0.182857	0.490196	0.254902
	N_{avg}	41.8		27	
	2σ	0.154485		0.191998	
	Shift	0.282351	-0.09465	0.201307	0.00305
	Sig ?	Yes	No	Yes	No
Reality Link	% Pre-	0.488095	0.10119	0.531532	0.117117
	% Post-	0.657143	0.15	0.61157	0.22314
	N_{avg}	42		27.75	
	2σ	0.116386		0.146037	
	Shift	0.169048	0.04881	0.080039	0.106023
	Sig ?	Yes	No	No	No
Math Link	% Pre-	0.30622	0.267943	0.273885	0.254777
	% Post-	0.525714	0.262857	0.49359	0.262821
	N_{avg}	41.8		31.4	
	2σ	0.154328		0.178341	
	Shift	0.219494	-0.00509	0.219704	0.008043
	Sig ?	Yes	No	Yes	No
Effort	% Pre-	0.542857	0.157143	0.624204	0.076433
	% Post-	0.542857	0.222857	0.557692	0.24359
	N_{avg}	42		31.4	
	2σ	0.128765		0.11127	
	Shift	0	0.065714	-0.06651	0.167157
	Sig ?	No	No	No	Yes

TABLE 5.4. Cluster-specific pre-/post-test comparisons of PBI and HBL student performance on the MPEX instrument from the Raw dataset.

MPEX Scores Contrast – MATCHED Dataset

MPEX Cluster		Physics by Inquiry Favorable	Physics by Inquiry Unfavorable	Hypothesis-Based Learning Favorable	Hypothesis-Based Learning Unfavorable
Independence	% Pre-	0.372549	0.328431	0.313725	0.401961
	% Post-	0.549505	0.267327	0.53	0.29
	N_{avg}	34		17	
	2σ	0.171159		0.240685	
	Shift	0.176956	-0.0611	0.216275	-0.11196
	Sig ?	Yes	No	No	No
Coherence	% Pre-	0.358824	0.311765	0.305882	0.270588
	% Post-	0.476471	0.294118	0.487805	0.329268
	N_{avg}	34		17	
	2σ	0.171076		0.242081	
	Shift	0.117647	-0.01765	0.181923	0.05868
	Sig ?	No	No	No	No
Concepts	% Pre-	0.313609	0.278107	0.27381	0.321429
	% Post-	0.576471	0.188235	0.55	0.175
	N_{avg}	33.8		16.8	
	2σ	0.171695		0.243193	
	Shift	0.262861	-0.08987	0.27619	-0.14643
	Sig ?	Yes	No	Yes	No
Reality Link	% Pre-	0.463235	0.095588	0.470588	0.088235
	% Post-	0.654412	0.154412	0.646154	0.184615
	N_{avg}	34		17	
	2σ	0.129157		0.176877	
	Shift	0.191176	0.058824	0.175566	0.09638
	Sig ?	Yes	No	No	No
Math Link	% Pre-	0.289941	0.295858	0.235294	0.294118
	% Post-	0.523529	0.270588	0.566265	0.228916
	N_{avg}	33.8		17	
	2σ	0.171996		0.241034	
	Shift	0.233589	-0.02527	0.330971	-0.0652
	Sig ?	Yes	No	Yes	No
Effort	% Pre-	0.511765	0.188235	0.654762	0.083333
	% Post-	0.541176	0.223529	0.60241	0.192771
	N_{avg}	34		16.8	
	2σ	0.152082		0.154424	
	Shift	0.029412	0.035294	-0.05235	0.109438
	Sig ?	No	No	No	No

TABLE 5.5. Cluster-specific pre-/post-test comparisons of PBI and HBL student performance on the MPEX instrument from the Matched dataset.

5.2.3 SPAMSS Analysis

Student SPAMSS scores were analyzed using an independent-samples t-test. This statistical procedure compares means for two groups and provides a t-test determining whether the two group means were different from one another. Ideally, the subjects should have been randomly assigned to the groups, insuring that any response differences were due to the treatment (or lack of treatment) and not to other factors. Given the assumed random student enrollment into either of the treatment sections, this assignment criterion was satisfied.

Analysis results for student SPAMSS scores are summarized in Table 5.7. This study was conducted to discern whether any differences among the two groups existed after instruction. The significance level for this study was chosen to be $p < 0.05$, a standard choice for statistical studies of this type. Interpretation of the statistical results was straightforward. When the significance level of a result was less than the significance criterion, statistically significant differences existed.

Upon analysis, the t-test for this dataset did not reach the chosen significance level. Therefore, no significant differences exist between the two groups, although the PBI average is slightly higher. Thus, either pedagogy results in effectively identical performance as assessed by this instrument. Additionally, it should be noted that the average score for each group was approximately 90% correct. This is most likely an indication that, despite exposure to different pedagogies, the advanced maturity of the student population played a decisive role in student scores. Thus, the assumption that this instrument was useful for students of this age may not have been appropriate.

5.2.4 Summary of SPAMSS Results

No statistically significant differences in student SPAMSS instrument scores existed after one semester of PBI or HBL instruction. The mean score of the PBI group was 45.29 (90.58%), while the HBL group mean was 44.69 (89.38%). Given the high mean scores for each group, the underlying assumption regarding the applicability of the SPAMSS instrument to this student population is likely false. The SPAMSS instrument, designed expressly for middle school students, is likely not fairly used on an audience of this age or educational background.

5.3 STEBI Analysis

5.3.1 STEBI Analysis Overview

Student data was collected using the STEBI-B and STEBI-A instruments, and analyzed according to the strategy presented by Riggs and Enochs.[18,20] Two major subdivisions exist among the STEBI instrument questions, which are summarized below.

1. **Personal Science Teaching Efficacy Belief (PSTEB)**: These items assess a respondent's self-perception of their ability to effectively teach science in a classroom and whether they can perform behaviors that will elicit the desired outcomes.

2. **Science Teaching Outcome Expectancy (STOE)**: Responses to these items indicate a person's self-assessment of a set of behaviors that will promote or help in achieving a particular educational result.

3. **Total Science Teaching Efficacy Belief (TOTAL)**: This score is simply the PSTEB and STOE sum.

Each instrument (STEBI-A or STEBI-B) uses identical question content in identical placement order within the instruments. The single difference is that the STEBI-B (pre-service) instrument is phrased in the future verb tense, as its intended audience is preservice teachers. The STEBI-A intended audience is inservice teachers. All discussion that follows implicitly assumes the differences among the instruments are accounted for by the author as necessary.

Students were given the STEBI-B (pre-service) instrument on the first class day, prior to any physics instruction or discussion. Students were instructed to choose answers to the 25 instrument questions assuming that they would be science teachers upon graduation. Following one complete semester of physics instruction, students completed the STEBI-A instrument. Students were again instructed to choose answers to the 25 instrument questions assuming that they would be science teachers upon graduation, addressing the small differences in phrasing within the instrument questions. The STEBI-B instrument may be referred to as the 'pre-test' in the following discussion, while the STEBI-A instrument may be referred to as the 'post-test'.

Student responses on each item were scored according to the rubric presented in Table 5.8.

Student SPAMSS Data By Group and Semester

	Fall 2003				Spring 2004		
PBI	45	36	41	47	41	43	47
	45	45	45	47	46	43	48
	44	49	47	46	47	46	45
	46	44	46	45	48	49	48
	48	43	45	46	44	44	46
HBL	37	44	42	45	46	47	47
	41	41	49	45	45	47	43
	45	46	45	45	43	47	
	47	46	47	47	44	43	
	43	44	41	46	43	49	

TABLE 5.6. PBI and HBL student performance on the SPAMSS instrument after one semester of instruction.

SPAMSS Exam Results
PBI Relative to HBL

PBI / HBL	Mean	N	SD	t	Significance
PBI	45.29	35	2.550	0.955	0.343
HBL	44.69	32	2.571		

TABLE 5.7. Analysis results for student SPAMSS instrument scores.

STEBI Response Scoring

Student Response	Points
Strongly Disagree	1
Disagree	2
Uncertain	3
Agree	4
Strongly Agree	5

TABLE 5.8. STEBI instrument scoring rubric used in this analysis.

Individual STEBI items were regrouped into PSTEB and STOE groups. Since items within a particular group were positively or negatively worded, some of the data was recoded to obtain consistent scoring within each group. Recoding was performed by inverting the scoring scale above to form uniformly 'positive' responses; that is, scores of 5 became 1, etc. Following recoding, group scores for each student were calculated by summing the scores of all items within the group. Table 5.9 summarizes the distribution of STEBI items into groups and indicates any necessary recoding.

5.3.2 STEBI Data Issues

One potentially serious problem exists with the STEBI dataset used in this analysis. Some student responses were incomplete, and some students did not complete both the STEBI-A and STEBI-B instruments. The dataset used in the STEBI analysis that follows includes only data from students who completed the instrument both pre- and post-instruction, since explicit comparisons would be made between and within the groups. This reduction in dataset size resulted in 34 sets of PBI data and 28 sets of HBL data. It was expected that this dataset would give the most accurate portrayal of the pedagogical influence, despite its reduced sample size.

5.3.3 STEBI Dataset

All student STEBI data included in this analysis is presented in Tables 5.10 and 5.11 .

STEBI Item Rescoring Matrix

Group	Item #	P/N Phrasing	Recoded?
PSTEB	2	P	No
	3	N	Yes
	5	P	No
	6	N	Yes
	8	N	Yes
	12	P	No
	17	N	Yes
	18	P	No
	19	N	Yes
	21	N	Yes
	22	N	Yes
	23	P	No
	24	N	Yes
STOE	1	P	No
	4	P	No
	7	P	No
	9	P	No
	10	N	Yes
	11	P	No
	13	N	Yes
	14	P	No
	15	P	No
	16	P	No
	20	N	Yes
	25	N	Yes

TABLE 5.9. STEBI instrument items requiring rescoring prior to analysis.

5.3.4 STEBI Analyses

Student STEBI scores were analyzed using an independent-samples t-test. This statistical procedure compares means for two groups and provides a t-test determining whether the two group means were different from one another. Ideally, the subjects should have been randomly assigned to the groups, insuring that any response differences were due to the treatment (or lack of treatment) and not to other factors. Given the assumed random student enrollment into either of the treatment sections, this assignment criterion was satisfied.

Four different independent-samples STEBI analyses were performed. The first study compared STEBI-B (pre-service) instrument responses among the treatment groups (PBI and HBL). The second study compared STEBI-B (pre-service) and STEBI-A (post-instruction) results for the PBI group, while the third study made the same comparison for the HBL group. The fourth study compared the STEBI-A (post-instruction) results for the PBI and HBL groups.

The significance criterion used for all studies was $p < 0.05$, which is standard for nearly all statistical studies of this type. Interpretation of the statistical results was straightforward. The t-test value for every comparison was reported, along with the significance level of each test. When the significance level of a result was less than the significance criterion, statistically significant differences existed. These significant results were indicated with an asterisk (*) in each table where they occurred.

Percentage changes in student scores are calculated by comparing the differences among the scores relative to the maximum overall score of 125 (25 questions at 5 points per question).

5.3.4.1 STUDY 1. STEBI-B instrument scores for PBI and HBL student groups are summarized in Table 5.12. This study was conducted to discern if any differences among the two groups existed prior to instruction.

No significant differences existed between the groups prior to instruction in Physics 1313. It is interesting to note, however, that the mean scores for HBL students were higher in every group by a non-significant margin. The lack of differences among these populations lends support to the random enrollment assumption, and indicates that the groups were not different prior to instruction.

5.3.4.2 STUDY 2. STEBI-B and STEBI-A instrument scores for the PBI student group are summarized in Table 5.13. The function of this study was to compare pre- and post- student responses to infer if any significant changes in student scores occurred as a result of PBI instruction.

While PBI student scores increased in every STEBI group, the only meaningful gain occurred in PSTE. The gain of approximately 4% in PSTEB score was significant, and was likely the reason that the total STEBI score was also significant. PBI STOE scores rose by approximately 0.2%, a non-significant increase. Students became significantly more confident in their self-assessed ability to teach science to their own students as a result of one semester's PBI instruction in Physics 1313. However, students did not change their beliefs regarding behaviors that would cause student learning to occur as a result of this instruction.

5.3.4.3 STUDY 3. STEBI-B and STEBI-A instrument scores for the HBL student group are summarized in Table 5.14. This study was performed for the same reasons as the PBI pre- / post- study above (Study 2).

HBL students made significant gains of approximately 4% in PSTEB scores as a result of one semester's HBL instruction in Physics 1313. Again, this significant increase most likely led to the significance of the increase in Total STEBI scores. The slight decline of 0.2% in STOE scores was not significant. HBL students became more confident in their ability to instruct their own students in science, but did not alter their opinions regarding what constituted effective causes of student learning.

5.3.4.4 STUDY 4. STEBI-A instrument scores for the PBI and HBL student groups are summarized in Table 5.15. This study assesses whether meaningful differences in the populations exist after one semester of instruction.

These results reveal that no statistically significant differences between the PBI and HBL populations exist after a single semester of Physics 1313 instruction. The PBI and HBL student populations were nonsignificantly different by approximately 1.5% in PSTEB scores. There were effectively no differences in the two population's STOE scores. However, it is interesting to note that HBL students had slightly higher PSTEB scores than PBI students. Given that no meaningful differences among the groups exist, it is likely that PBI or HBL are equally effective in significantly increasing pre-service teachers' perceptions of their ability to teach science. These changes occur without altering student beliefs underlying the classroom behaviors constituting effective science teaching.

5.3.5 Summary of STEBI Results

Upon analysis, no significant initial differences existed between PBI students and HBL students prior to instruction. PBI instruction caused significant increases in student PSTEB scores of 4.79 (3.83%), and no significant changes in STOE scores. HBL instruction caused significant increases in student PSTEB scores of 5.04 (4.03%), and no significant changes in STOE scores. STEBI instrument scores for PBI and HBL students were not significantly different after one semester of instruction. It seems likely that either PBI or HBL are equally effective at altering student perceptions of their own ability to provide instruction in science.

5.4 Exam Item Data Analysis

5.4.1 Exam Item Analysis Overview

Students completing the Midterm and Final semester exams were assessed using problems from all four course content areas. Three content areas were chosen for inclusion in the analysis presented in this dissertation: Light and Color (midterm exam, 2 questions), Astronomy by Sight (final exam, 1 question), and Electric Circuits (final exam, 1 question). These four Exam Item problems had been identified prior to the exams as 'capstone' items: these problems represent student opportunities to demonstrate the ability to analyze a relatively complex situation and synthesize the course material into a coherent solution strategy.

5.4.2 Exam Item Data Issues

Student scores were assessed by this researcher in the following manner. The Exam Items were graded in the same manner as other exam problems. Exam Item problems were placed in random order and graded without regard to course section or student. That is, all Exam Item problems were graded as fairly as this instructor was able. Neither course section received deliberately different or preferential grading.

Two major issues exist for the data presented in this analysis. First, this analysis should be considered preliminary, as these issues may pose significant problems. As student performance on Exam Items was evaluated by the author, a skeptical evaluator could rightly assert that insufficient care was exercised in designing this study. While this assertion may be true, pristine photocopied student data for all Exam Items has been archived with intent for an extensive future double-blind analysis. However, the twin issues of funding and timing have eliminated this option for the purposes of this dissertation.

Dataset size issues also exist for this dataset. All students completing either the midterm or final exams added data for potential use in this dataset. This analysis includes partial data from the fall 2003 semester. Student final exam data from the fall 2003 semester was corrupted and had problems sufficient for exclusion from this analysis. The midterm exam data was not corrupted and was included in the analysis. No corrupted data existed for the spring 2004 semester; all student data was analyzed. Thus, the midterm Exam Item dataset included 34 PBI students and 32 HBL students, while the final exam dataset had 14 PBI students and 12 HBL students. These small final exam dataset sample sizes were sufficient for statistical analysis, which specifies a minimum sample size of 12 subjects.[22]

Given the potential problems associated with this analysis, the following disclaimer should be noted.

THESE ANALYSES ARE PRELIMINARY.

5.4.3 Exam Item Dataset

Student scores on the four Exam Items are presented in Tables 5.16 and 5.17. Corrupted fall 2003 final exam data was denoted 'X'.

Student STEBI (Pre- and Post-test) Data By Group – Fall 2003 Semester

		STEBI-B (Pre-Test)			STEBI-A (Post-Test)		
	Student	PSTEB	STOE	TOTAL	PSTEB	STOE	TOTAL
PBI	1	40	35	75	41	38	79
	2	45	38	83	43	37	80
	3	34	37	71	36	36	72
	4	30	42	72	51	40	91
	5	34	37	71	41	43	84
	6	32	44	76	41	43	84
	7	37	47	84	41	38	79
	8	28	41	69	29	37	66
	9	38	41	79	42	41	83
	10	36	43	79	39	46	85
	11	36	33	69	47	40	87
	12	28	44	72	44	42	86
	13	38	39	77	42	40	82
	14	44	38	82	47	38	85
	15	46	42	88	37	45	82
	16	27	46	73	31	35	66
	17	35	43	78	36	40	76
	18	37	40	77	45	38	83
	19	44	46	90	49	41	90
	20	33	30	63	40	39	79
HBL	1	48	32	80	41	34	75
	2	48	41	89	44	42	86
	3	45	41	86	48	42	90
	4	48	47	95	51	45	96
	5	40	44	84	41	40	81
	6	38	29	67	41	35	76
	7	35	37	72	43	43	86
	8	46	38	84	43	38	81
	9	38	36	74	48	42	90
	10	41	53	94	43	48	91
	11	43	38	81	50	39	89
	12	37	40	77	39	39	78
	13	40	39	79	43	42	85
	14	30	44	74	36	45	81
	15	25	36	61	41	41	82
	16	37	41	78	42	41	83
	17	29	39	68	46	44	90
	18	48	32	80	41	34	75

TABLE 5.10. Fall 2003 student STEBI instrument scores used in this analysis.

Student STEBI (Pre- and Post-test) Data By Group – Spring 2004 Semester

		STEBI-B (Pre-Test)			STEBI-A (Post-Test)		
	Student	PSTEB	STOE	TOTAL	PSTEB	STOE	TOTAL
PBI	1	47	37	84	54	38	92
	2	50	35	85	45	40	85
	3	47	42	89	47	41	88
	4	48	40	88	53	43	96
	5	39	38	77	41	41	82
	6	34	40	74	41	38	79
	7	36	41	77	45	40	85
	8	37	45	82	43	49	92
	9	44	37	81	52	44	96
	10	49	37	86	50	31	81
	11	25	35	60	35	43	78
	12	40	36	76	44	38	82
	13	42	43	85	43	39	82
	14	38	44	82	46	43	89
HBL	1	42	44	86	40	36	76
	2	43	44	87	47	38	85
	3	45	38	83	50	29	79
	4	38	41	79	40	34	74
	5	42	51	93	52	39	91
	6	39	37	76	45	41	86
	7	37	34	71	48	36	84
	8	38	41	79	41	44	85
	9	46	45	91	54	45	99
	10	48	37	85	52	46	98
	11	29	47	76	47	39	86

TABLE 5.11. Spring 2004 student STEBI instrument scores used in this analysis.

STEBI Pre-Test Results
PBI Relative to HBL

Comparison	PBI / HBL	Mean	N	SD	t	Significance
Total	PBI	78.08	34	7.259	1.121	0.267
	HBL	80.32	28	8.424		
PSTEB	PBI	38.18	34	6.649	0.999	0.322
	HBL	39.82	28	6.207		
STOE	PBI	39.91	34	4.003	0.496	0.622
	HBL	40.50	28	5.337		

TABLE 5.12. Comparison results between PBI and HBL students prior to instruction.

STEBI Results – PBI Section

Comparison	Pre- / Post-	Mean	N	SD	t	Significance
Total	Pre-	78.09	34	7.259	3.996	< 0.001*
	Post-	83.12		6.901		
PSTEB	Pre-	38.18	34	6.649	5.095	< 0.001*
	Post-	42.97		5.802		
STOE	Pre-	39.91	34	4.003	0.299	0.767
	Post-	40.15		3.395		

TABLE 5.13. Comparative analysis of PBI student STEBI scores as a result of one semester's instruction.

STEBI Results – HBL Section

Comparison	Pre- / Post-	Mean	N	SD	t	Significance
Total	Pre-	80.32	28	8.424	3.054	0.005*
	Post-	85.11		6.618		
PSTEB	Pre-	39.82	28	6.207	4.499	< 0.001*
	Post-	44.86		4.608		
STOE	Pre-	40.50	28	5.337	0.248	0.806
	Post-	40.25		4.283		

TABLE 5.14. Comparative analysis of HBL student STEBI scores as a result of one semester's instruction.

STEBI Post-Test Results
PBI Relative to HBL

Comparison	PBI / HBL	Mean	N	SD	t	Significance
Total	PBI	83.12	34	6.901	1.151	0.254
	HBL	85.11	28	6.618		
PSTEB	PBI	42.97	34	5.802	1.395	0.168
	HBL	44.86	28	4.608		
STOE	PBI	40.15	34	3.395	0.106	0.916
	HBL	40.25	28	4.283		

TABLE 5.15. Comparison results between PBI and HBL students after one semester of instruction.

5.4.4 Exam Item Analyses

Student Exam Item scores were analyzed using an independent-samples t-test. This statistical procedure compares means for two groups and provides a t-test determining whether the two group means were different from one another. Ideally, the subjects should have been randomly assigned to the groups, insuring that any response differences were due to the treatment (or lack of treatment) and not to other factors. Given the assumed random student enrollment into either of the treatment sections, this assignment criterion was satisfied.

Four different independent-samples Exam Item analyses were performed, one for each Exam Item. Analysis results for student Exam Item scores were summarized in Table 5.18. These studies were conducted to discern whether any differences among the two groups existed after instruction. The significance level for these studies was chosen to be $p < 0.05$, a standard choice for statistical studies of this type. Interpretation of the statistical results was straightforward. The t-test value for every comparison was reported, along with the significance level of each test. When the significance level of a result was less than the significance criterion, statistically significant differences existed. These significant results were indicated with an asterisk (*) where they occurred.

Exam Item Dataset – Fall 2003

PBI				HBL			
Midterm		Final		Midterm		Final	
LC 1	LC 2	AbS	EC	LC 1	LC 2	AbS	EC
5	5	X	X	5	3	X	X
2	4	X	X	2	3	X	X
3	3	X	X	3	3	X	X
2	3	X	X	3	4	X	X
2	2	X	X	4	5	X	X
1	4	X	X	3	1	X	X
2	4	X	X	3	1	X	X
2	4	X	X	3	2	X	X
4	3	X	X	1	2	X	X
5	4	X	X	2	2	X	X
4	5	X	X	2	2	X	X
2	1	X	X	3	3	X	X
2	3	X	X	3	4	X	X
3	4	X	X	3	4	X	X
3	4	X	X	5	5	X	X
2	2	X	X	2	3	X	X
2	2	X	X	2	4	X	X
2	5	X	X	2	4	X	X
2	3	X	X	2	3	X	X
2	1	X	X	2	2	X	X

TABLE 5.16. Fall 2003 Exam Item scores of PBI and HBL students after one semester of instruction.

Exam Item Dataset – Spring 2004

PBI				HBL			
Midterm		Final		Midterm		Final	
LC 1	LC 2	AbS	EC	LC 1	LC 2	AbS	EC
5	4	5	3	4	4	5	3
4	3	5	1	4	5	5	1
4	4	2	2	2	4	2	2
5	5	5	4	3	3	5	4
2	4	3	1	5	4	3	1
4	4	4	3	3	4	4	3
3	3	2	3	5	5	2	3
2	4	1	3	3	4	1	3
3	5	2	2	5	5	2	2
5	2	3	3	2	4	3	3
4	3	1	2				
4	4	3	3				
4	3	2	2				
2	3	4	2				

TABLE 5.17. Spring 2003 Exam Item scores of PBI and HBL students after one semester of instruction.

Exam Item Analysis Results
PBI Relative to HBL

Exam Item	Group	Mean	N	SD	t	Significance
Midterm (LC 1)	PBI	3.06	34	1.187	0.237	0.814
	HBL	3.13	32	1.157		
Midterm (LC 2)	PBI	3.46	34	1.067	0.155	0.877
	HBL	3.5	32	1.191		
Final (AbS)	PBI	3.00	14	1.414	0.158	0.875
	HBL	3.08	12	1.240		
Final (EC)	PBI	2.43	14	0.852	2.126	0.044*
	HBL	3.33	12	1.303		

TABLE 5.18. Analysis results of Exam Item scores for PBI and HBL students after one semester of instruction.

5.4.5 Summary of Exam Item Analysis Results

No significant Exam Item differences existed after one semester of physics instruction in Light and Color or Astronomy by Sight content. However, mean scores of the HBL group were larger by a nonsignificant margin in every case.

However, significant differences among the group means existed for the Electric Circuits question. One semester of physics instruction using HBL caused significantly improved student performance on this Electric Circuits problem.

5.4.6 Thacker Comparison and Analysis

Thacker, et al[73] conducted a study similar to the Exam Item study above. In that study, PBI was used to instruct a group of elementary education students, and traditional instruction methods (lectures, recitations, and laboratories) were used to instruct an honors physics course, an engineering physics course, and a physics survey course for non-science or non-technical majors. All courses met for 6 or 7 hours per week, and covered DC circuit analysis. The honors and survey courses spent 1 week on DC circuits, the engineering physics course spent 2 weeks, and the inquiry course spent 2.5 weeks.

Two two-part Electric Circuits problems were created and given to the course instructors, all of whom agreed that the problems were appropriate for their students. One of the problems was able to be answered conceptually; one required at least some mathematical analysis. These problems were termed synthesis and analysis problems, respectively. Each problem presented a situation, asked for a result, and asked for an explanation for the answers. Students in each course encountered the synthesis and analysis problems on an exam. Note that the inquiry students did not have any information regarding Ohm's Law or voltage prior to receiving the problems; students in all other courses had covered all relevant DC circuits material. Student solutions were obtained and graded according to a rubric. To eliminate grader subjectivity, only student answers that completely answered the problems (including explanations) were scored 'correct'.

The resulting student performance was quite startling. Inquiry students outscored the honors students by a margin in excess of 7:1 (29% vs. 4%), and outscored the engineering students by a margin of nearly 15:1 (29% vs. 2%) on the synthesis problem. None of the survey students received full credit on this problem. On the analysis problem, where mathematically-oriented courses enjoyed a distinct advantage, honors students outscored inquiry students by a margin in excess of 3:1 (57% vs. 17%), but the inquiry students outperformed the engineering students by a nearly 3:1 (17% vs. 6%) margin. Only 1 student in the survey course received full credit on the analysis problem. All differences in group performance were significant at $p < 0.05$ or less.

In that study, Thacker, et al., concluded that PBI inquiry instruction results for elementary education students was superior to traditional instruction for all classes, with the exception of the honors course. Problem solution results indicate that either of these groups did better on the type of problem they were most used to encountering.

In short, PBI instruction achieved significantly better results on these problems than traditional instruction for elementary education, engineering, and non-science majors.

Given these results, the Exam Item analysis above might suggest another comparison. Although the synthesis and analysis problems were different from the Electric Circuits Exam Item, a similar comparison may be justified. Recall that the single significant difference in Physics 1313 student performance occurred on this question. Given the same style of comparison, it is not unreasonable to infer a transitive relationship amongst pedagogies: HBL was significantly better than PBI on the Electric Circuits Exam Item above, while PBI was significantly better than traditional instruction in the Thacker study. Thus, it seems likely that HBL could be expected to be superior to traditional instruction.

5.5 Conclusions Supported by This Dissertation's Analyses

The analyses presented above reveal many interesting changes caused by the PBI and HBL pedagogies. A synopsis of major results indicates:

1. **All populations of student subjects were statistically similar prior to instruction.** No meaningful differences existed in either self-efficacy or physics expectations, fall or spring. This indicates that the student population is relatively homogeneous and stable in composition throughout the academic year. These results further support the assumptions underlying the analyses conducted, since the samples were combined for analysis.

2. **HBL and PBI cause statistically similar significant gains in elementary education students' self-efficacy scores.** Both populations experienced a statistically meaningful increase in PSTEB scores of approximately 4% as a result of instruction.

3. **HBL and PBI cause statistically similar gains in elementary education students'physics expectations.** Student expectations in every MPEX

cluster were altered in the same manner by similar amounts as a result of PBI or HBL instruction. Both groups of students changed expectations towards enhanced agreement with the expert positions, unlike students experiencing traditional physics instruction.

4. **After instruction, no significant differences existed between groups in student STEBI scores.** Both PBI and HBL students achieved similar final STEBI scores after instruction. Thus, these pedagogies were equally effective at increasing student self-efficacy.

5. **No significant differences existed between groups in student MPEX scores after instruction.** PBI and HBL students had largely indistinguishable MPEX scores after instruction. Thus, neither pedagogy was more effective at increasing student physics expectations.

6. **Analysis revealed that the SPAMSS instrument is likely inappropriate for this audience.** PBI and HBL groups averaged approximately 90% correct on the instrument, with no significant differences retained between them.

7. **No significant differences in Exam Item performance existed for Light and Color or Astronomy by Sight problems.** Students in either group tended to perform at nearly the same competency level on all three problems.

8. **HBL caused a significant student score improvement on the Electric Circuits problem.** HBL student scores on this problem were 37% higher than PBI students'. Taken with the evidence presented by Thacker, et al., HBL may compare even more favorably with traditional electric circuits instruction than PBI.

The major conclusion of this dissertation's analysis is that HBL produces largely the same results as PBI, providing explicit evidence that open and directed inquiry pedagogies can be equally effective. This result is quite scarce in the literature if it exists at all, as the author had no success in finding similar results.

5.6 Directions for Future Research

Much further work remains to be done in establishing HBL as a mainstream pedagogy. This will happen only with further study of the mechanisms HBL utilizes to accomplish its gains. Several directions for future study present themselves.

PBI content was adapted for use using HBL in the studies presented above. This may provide an impediment to effectively using HBL in the classroom even when addressing the same physics content. Further studies may open this arena by allowing HBL investigation of identical material in an unconstrained manner, followed by an 'Exam Item' comparison as above.

This author is convinced that HBL's main strength lies in providing students the intellectual tools necessary to confront, study, and understand previously unknown situations. No studies of this type have been attempted, but it is likely that HBL students would excel in this arena.

Likewise, PBI does not make explicit connections to the underlying process used to study unknown situations. A detailed comparison of the student ability to perform process on a particular 'process-based' problem may reveal the mechanisms used by students experiencing either pedagogy to perform science process.

Furthermore, no instrument explicitly assessing student science process skills exists for audiences of this age and educational background. This researcher feels that such an instrument is sorely needed and that it would reveal new insight into student science understanding and use.

Comparisons between HBL and other pedagogies need to be performed, as they will yield further information necessary to adequately understand HBL. This type of study should also study populations other than elementary education majors. It may well be the case that HBL is superior to traditional instruction (as indicated above), and that it is especially effective for certain audiences or student genders. Obviously, one major shortcoming of the analyses above is that they are only meaningful for female elementary education majors. Further study regarding HBL's effectiveness for a male audience is required.

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APPENDICES

APPENDIX A

APPENDIX 1

A copy of the IRB approval letter for the studies conducted in this dissertation appears in Figure A.1.

Oklahoma State University
Institutional Review Board

Protocol Expires: 9/10/2004

Date: Thursday, September 11, 2003 IRB Application No AS0418

Proposal Title: Assessing the Effectiveness of the Hypothesis-Based Learning Methodology

Principal
Investigator(s):

Charles E. Hasty	Bruce J. Ackerson
349 Physical Science	215 Physical Science
Stillwater, OK 74078	Stillwater, OK 74078

Reviewed and
Processed as: Exempt

Approval Status Recommended by Reviewer(s): Approved

Dear PI :

Your IRB application referenced above has been approved for one calendar year. Please make note of the expiration date indicated above. It is the judgment of the reviewers that the rights and welfare of individuals who may be asked to participate in this study will be respected, and that the research will be conducted in a manner consistent with the IRB requirements as outlined in section 45 CFR 46.

As Principal Investigator, it is your responsibility to do the following:

1. Conduct this study exactly as it has been approved. Any modifications to the research protocol must be submitted with the appropriate signatures for IRB approval.
2. Submit a request for continuation if the study extends beyond the approval period of one calendar year. This continuation must receive IRB review and approval before the research can continue.
3. Report any adverse events to the IRB Chair promptly. Adverse events are those which are unanticipated and impact the subjects during the course of this research; and
4. Notify the IRB office in writing when your research project is complete.

Please note that approved projects are subject to monitoring by the IRB. If you have questions about the IRB procedures or need any assistance from the Board, please contact Sharon Bacher, the Executive Secretary to the IRB, in 415 Whitehurst (phone: 405-744-5700, sbacher@okstate.edu).

Sincerely,

Carol Olson

Carol Olson, Chair
Institutional Review Board

Figure A.1. IRB approval form for the studies conducted in this dissertation.

APPENDIX B

INSTRUMENTS

The instruments used to assess student performance appear in this Appendix. All instruments are present, excepting the SPAMSS instrument. It is not present due to copyright issues.

B.1 STEBI Instruments

The STEBI-B (pre-test) instrument appears in Figure B.1, while the STEBI-A (post-test) instrument appears in Figure B.2.

B.2 MPEX Instrument

The MPEX instrument appears in Figures B.3 and B.4.

B.3 Exam Item Instruments

The Exam Item instruments appear in the following Figures.

B.3.1 Exam Item: Light and Color 1

The first Light and Color Exam Item appears in Figure B.5.

B.3.2 Exam Item: Light and Color 2

The second Light and Color Exam Item appears in Figure B.6.

B.3.3 Exam Item: Astronomy by Sight

The Astronomy by Sight Exam Item appears in Figure B.7.

B.3.4 Exam Item: Electric Circuits

The Electric Circuits Exam Item appears in Figure B.8.

STEBI Form B (Preservice)

Please indicate the degree to which you agree or disagree with each statement below by circling the appropriate letters to the right of each statement.

SA = Strongly Agree A = Agree UN = Uncertain D = Disagree SD = Strongly Disagree

1.	When a student does better than usual in science, it is often because the teacher exerted a little extra effort.	SA A UN D SD
2.	I will continually find better ways to teach science.	SA A UN D SD
3.	Even if I try very hard, I will not teach science as well as I will most subjects.	SA A UN D SD
4.	When the science grades of students improve, it is often due to their teacher having found a more effective teaching approach.	SA A UN D SD
5.	I know the steps necessary to teach science concepts effectively.	SA A UN D SD
6.	I will not be very effective in monitoring science experiments.	SA A UN D SD
7.	If students are underachieving in science, it is most likely due to ineffective science teaching.	SA A UN D SD
8.	I will generally teach science ineffectively.	SA A UN D SD
9.	The inadequacy of a student's science background can be overcome by good teaching.	SA A UN D SD
10.	The low science achievement of some students cannot generally be blamed on their teachers.	SA A UN D SD
11.	When a low-achieving child progresses in science, it is usually due to extra attention given by the teacher.	SA A UN D SD
12.	I understand science concepts well enough to be effective in teaching elementary science.	SA A UN D SD
13.	Increased effort in science teaching produces little change in some students' science achievement.	SA A UN D SD
14.	The teacher is generally responsible for achievement of students in science.	SA A UN D SD
15.	Students' achievement in science is directly related to their teacher's effectiveness in science teaching.	SA A UN D SD
16.	If parents comment that their child is showing more interest in science at school, it is probably due to the performance of the child's teacher.	SA A UN D SD
17.	I will find it difficult to explain to students why science experiments work.	SA A UN D SD
18.	I will typically be able to answer students' science questions.	SA A UN D SD
19.	I wonder if I will have the necessary skills to teach science.	SA A UN D SD
20.	Given a choice, I will not invite the principal to evaluate my science teaching.	SA A UN D SD
21.	When a student has difficulty understanding a science concept, I will usually be at a loss as to how to help the student understand it better.	SA A UN D SD
22.	When teaching science, I will usually welcome student questions.	SA A UN D SD
23.	I do not know what to do to turn students on to science.	SA A UN D SD

Enochs, L. G. & Riggs, I. M. (1990). Further Development of an Elementary Science Teaching Efficacy Belief Instrument: A preservice elementary scale. School Science and Mathematics,90(8), 695-706.

Figure B.1. STEBI-B (pre-test) instrument used in this dissertation.

STEBI Form A

Please indicate the degree to which you agree or disagree with each statement below by circling the appropriate letters to the right of each statement.

SA = Strongly Agree A = Agree UN = Uncertain D = Disagree SD = Strongly Disagree

1.	When a student does better than usual in science, it is often because the teacher exerted a little extra effort.	SA A UN D SD
2.	I am continually finding better ways to teach science.	SA A UN D SD
3.	Even when I try very hard, I do not teach science as well as I do most subjects.	SA A UN D SD
4.	When the science grades of students improve, it is often due to their teacher having found a more effective teaching approach.	SA A UN D SD
5.	I know the steps necessary to teach science concepts effectively.	SA A UN D SD
6.	I am not very effective in monitoring science experiments.	SA A UN D SD
7.	If students are underachieving in science, it is most likely due to ineffective science teaching.	SA A UN D SD
8.	I generally teach science ineffectively.	SA A UN D SD
9.	The inadequacy of a student's science background can be overcome by good teaching.	SA A UN D SD
10.	The low science achievement of some students cannot generally be blamed on their teachers.	SA A UN D SD
11.	When a low-achieving child progresses in science, it is usually due to extra attention given by the teacher.	SA A UN D SD
12.	I understand science concepts well enough to be effective in teaching elementary science.	SA A UN D SD
13.	Increased effort in science teaching produces little change in some students' science achievement.	SA A UN D SD
14.	The teacher is generally responsible for the achievement of students in science.	SA A UN D SD
15.	Students' achievement in science is directly related to their teacher's effectiveness in science teaching.	SA A UN D SD
16.	If parents comment that their child is showing more interest in science at school, it is probably due to the performance of the child's teacher.	SA A UN D SD
17.	I find it difficult to explain to students why science experiments work.	SA A UN D SD
18.	I am typically able to answer students' science questions.	SA A UN D SD
19.	I wonder if I have the necessary skills to teach science.	SA A UN D SD
20.	Effectiveness in science teaching has little influence on the achievement of students with low motivation.	SA A UN D SD
21.	Given a choice, I would not invite the principal to evaluate my science teaching.	SA A UN D SD
22.	When a student has difficulty understanding a science concept, I am usually at a loss as to how to help the student understand it better.	SA A UN D SD
23.	When teaching science, I usually welcome student questions.	SA A UN D SD
24.	I do not know what to do to turn students on to science.	SA A UN D SD
25.	Even teachers with good science teaching abilities cannot help some kids to learn science.	SA A UN D SD

Riggs, I. M. & Enochs, L. G., (1990).Toward the development of an elementary teacher's science teaching efficacy belief instrument.Science Education, 74(6), 625-637.

Figure B.2. STEBI-A (post-test) instrument used in this dissertation.

Student Expectations in University Physics:
The Maryland Physics Expectations Survey

Here are 34 statements which may or may not describe your beliefs about this course. You are asked to rate each statement by circling a number between 1 and 5 where the numbers mean the following:

1: Strongly Disagree	2: Disagree	3: Neutral	4: Agree	5: Strongly Agree

Answer the questions by circling the number that best expresses your feeling. Work quickly. Don't over-elaborate the meaning of each statement. They are meant to be taken as straightforward and simple. If you don't understand a statement, leave it blank. If you understand, but have no strong opinion, circle 3. If an item combines two statements and you disagree with either one, choose 1 or 2.

1	All I need to do to understand most of the basic ideas in this course is just read the text, work most of the problems, and/or pay close attention in class.	1 2 3 4 5
2	All I learn from a derivation or proof of a formula is that the formula obtained is valid and that it is OK to use it in problems.	1 2 3 4 5
3	I go over my class notes carefully to prepare for tests in this course.	1 2 3 4 5
4	"Problem solving" in physics basically means matching problems with facts or equations and then substituting values to get a number.	1 2 3 4 5
5	Learning physics made me change some of my ideas about how the physical world works.	1 2 3 4 5
6	I spend a lot of time figuring out and understanding at least some of the derivations or proofs given either in class or in the text.	1 2 3 4 5
7	I read the text in detail and work through many of the examples given there.	1 2 3 4 5
8	In this course, I do not expect to understand equations in an intuitive sense; they must just be taken as givens.	1 2 3 4 5
9	The best way for me to learn physics is by solving many problems rather than by carefully analyzing a few in detail.	1 2 3 4 5
10	Physical laws have little relation to what I experience in the real world.	1 2 3 4 5
11	A good understanding of physics is necessary for me to achieve my career goals. A good grade in this course is not enough.	1 2 3 4 5
12	Knowledge in physics consists of many pieces of information each of which applies primarily to a specific situation.	1 2 3 4 5
13	My grade in this course is primarily determined by how familiar I am with the material. Insight or creativity has little to do with it.	1 2 3 4 5
14	Learning physics is a matter of acquiring knowledge that is specifically located in the laws, principles, and equations given in class and/or in the textbook.	1 2 3 4 5
15	In doing a physics problem, if my calculation gives a result that differs significantly from what I expect, I'd have to trust the calculation.	1 2 3 4 5

MPEX *1*

Figure B.3. MPEX instrument used in this dissertation - page 1.

16	The derivations or proofs of equations in class or in the text has little to do with solving problems or with the skills I need to succeed in this course.	1 2 3 4 5
17	Only very few specially qualified people are capable of really understanding physics.	1 2 3 4 5
18	To understand physics, I sometimes think about my personal experiences and relate them to the topic being analyzed.	1 2 3 4 5
19	The most crucial thing in solving a physics problem is finding the right equation to use.	1 2 3 4 5
20	If I don't remember a particular equation needed for a problem in an exam there's nothing much I can do (legally!) to come up with it.	1 2 3 4 5
21	If I came up with two different approaches to a problem and they gave different answers, I would not worry about it; I would just choose the answer that seemed most reasonable. (Assume the answer is not in the back of the book.)	1 2 3 4 5
22	Physics is related to the real world and it sometimes helps to think about the connection, but it is rarely essential for what I have to do in this course.	1 2 3 4 5
23	The main skill I get out of this course is learning how to solve physics problems.	1 2 3 4 5
24	The results of an exam don't give me any useful guidance to improve my understanding of the course material. All the learning associated with an exam is in the studying I do before it takes place.	1 2 3 4 5
25	Learning physics helps me understand situations in my everyday life.	1 2 3 4 5
26	When I solve most exam or homework problems, I explicitly think about the concepts that underlie the problem.	1 2 3 4 5
27	"Understanding" physics basically means being able to recall something you've read or been shown.	1 2 3 4 5
28	Spending a lot of time (half an hour or more) working on a problem is a waste of time. If I don't make progress quickly, I'd be better off asking someone who knows more than I do.	1 2 3 4 5
29	A significant problem in this course is being able to memorize all the information I need to know.	1 2 3 4 5
30	The main skill I get out of this course is to learn how to reason logically about the physical world.	1 2 3 4 5
31	I use the mistakes I make on homework and on exam problems as clues to what I need to do to understand the material better.	1 2 3 4 5
32	To be able to use an equation in a problem (particularly in a problem that I haven't seen before), I need to know more than what each term in the equation represents.	1 2 3 4 5
33	It is possible to pass this course (get a "C" or better) without understanding physics very well.	1 2 3 4 5
34	Learning physics requires that I substantially rethink, restructure, and reorganize the information that I am given in class and/or in the text.	1 2 3 4 5

Figure B.4. MPEX instrument used in this dissertation - page 2.

1) In the situation to the right, the painted surface has the word "magenta" in magenta paint on a yellow background. Determine the color of the acetate used if the person viewing the surface through the acetate sees the word "magenta" in blue on a green background. Provide specific reasons to support your answer.

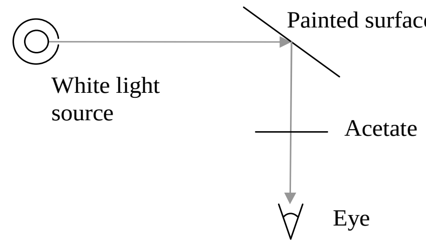


Figure B.5. Light and Color Exam Item 1 used in this dissertation.

2) Three light sources of similar brightness are used to project an image onto a screen. Two of the lights are long filament bulbs, and the third is a point source. A mask having a star–shaped hole (shown at right) is placed between the bulbs and the screen. Predict the shape of the image cast on the screen if the bulbs are arranged in a capital "T" shape followed by a period: "T.". Provide specific reasons for your answer.

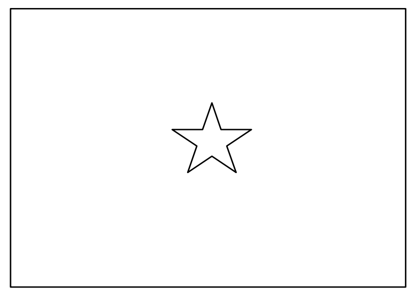
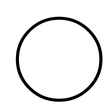


Figure B.6. Light and Color Exam Item 2 used in this dissertation.

3) Today, you look outside and see the moon has completed three–quarters of its transit across the sky. Determine the **present–day** moon phase and time of the observation using the following information. Nine days ago, the moon was in the same position at 12:00 am. Carefully explain your answers. You may assume a "perfect day"; i.e., sunrise at 6:00 am, sunset at 6:00 pm for both days.

Important: Do not forget that there are two **different** days discussed above!

Current Moon Phase: 

Current observation time: _______________

Figure B.7. Astronomy by Sight Exam Item used in this dissertation.

4) Relative to an indicator bulb, predict the brightness of all bulbs in this circuit as well as the current through the battery. Give specific reasons for your answer, assuming all bulbs are identical and that the battery is the same as that in an indicator circuit.

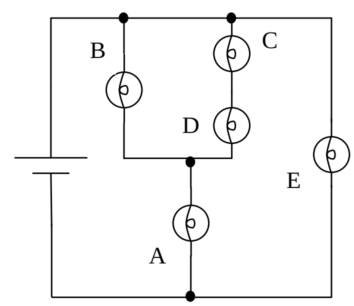


Figure B.8. Electric Circuits Exam Item used in this dissertation.

APPENDIX C

HBL COURSE CONTENT

Extensive HBL course content was created to parallel the content covered in the PBI class section, and is presented in this Appendix.

C.1 Course Schedules

C.1.1 PBI

The schedule of PBI class activities for the fall 2003 semester is presented in this section.

PHYSICS 1313
Schedule Page
Fall 2003

Class Week #	Class Week Begins	Module	Day of the Week			McDermott's Physics By Inquiry Module and Topic (Class Activities)	Assignment Due on Date Listed (Homework Assignments)
			M	W	F		
1	08/18/03	AbS				Introduction to the course. STEBI and MPEX survey completion. Operational Definitions. Moon Observation and Sun-Plot Fundamentals. Begin AbS - learn data techniques. Do ONLY the following sections: Ex. 1.1, 1.2, 2.1, 2.2, 2.7 (a,b, and d), PBI - I, p. 325.	
		AbS LC				Complete AbS Data Techniques. Begin LC: Ex. 1.1, PBI - I, p. 225. Homework Checkpoint: LC §1.1	
		LC				Continue LC Progress Check: LC §1.6	**HW1**: LC 2.2, 2.4, p. 260-261. Supplemental Homework Handout.
2	08/25/03	LC				Continue LC SKIP section 2.2. Progress Check: LC §2.4	
		LC				Continue LC Homework Checkpoint: LC §2.7 Finalize Midterm Skip Day. Finalize Final Exam time.	SP1
		AbS				Resume AbS, PBI - I, Ex. 1.4, p. 327. Progress Check: AbS §1.6	**HW2**: LC 1.2, 2.5, 2.6, p. 259-262. MO1 & MO2
3	09/01/03					**LABOR DAY** **University Holiday - NO CLASS !!!** :-)	
		LC				Resume LC Complete LC §2.9. SKIP all section 3 material: §3.1 - §3.5 Resume LC with §4.1. Homework Checkpoint: LC §4.1	
		LC				Continue LC	**HW3**: LC 2.8, 2.9, 2.10, p. 263-

Figure C.1. PBI Section Schedule - Fall 2003 - page 1

PHYSICS 1313
Schedule Page
Fall 2003

Class Week #	Class Week Begins	Module	Day of the Week			McDermott's Physics By Inquiry Module and Topic (Class Activities)	Assignment Due on Date Listed (Homework Assignments)
			M	W	F		
1	08/18/03	AbS	■			Introduction to the course. STEBI and MPEX survey completion. Operational Definitions. Moon Observation and Sun-Plot Fundamentals. Begin AbS - learn data techniques. Do ONLY the following sections: Ex. 1.1, 1.2, 2.1, 2.2, 2.7 (a,b, and d), PBI - I, p. 325.	
		AbS LC		■		Complete AbS Data Techniques. Begin LC: Ex. 1.1, PBI - I, p. 225. Homework Checkpoint: LC §1.1	
		LC			■	Continue LC Progress Check: LC §1.6	**HW1**: LC 2.2, 2.4, p. 260-261. Supplemental Homework Handout.
2	08/25/03	LC	■			Continue LC SKIP section 2.2. Progress Check: LC §2.4	
		LC		■		Continue LC Homework Checkpoint: LC §2.7 Finalize Midterm Skip Day. Finalize Final Exam time.	SP1
		AbS			■	Resume AbS, PBI - I, Ex. 1.4, p. 327. Progress Check: AbS §1.6	**HW2**: LC 1.2, 2.5, 2.6, p. 259-262. MO1 & MO2
3	09/01/03		■			**LABOR DAY** **University Holiday - NO CLASS !!!** :-)	
		LC		■		Resume LC Complete LC §2.9. SKIP all section 3 material: §3.1 - §3.5 Resume LC with §4.1. Homework Checkpoint: LC §4.1	
		LC			■	Continue LC	**HW3**: LC 2.8, 2.9, 2.10, p. 263-

Figure C.2. PBI Section Schedule - Fall 2003 - page 2

						Progress Check: HT §3.1	
		HT				Continue HT Homework Checkpoint: HT §3.5	SP4
		HT				Continue HT Progress Check: HT §4.2	**HW8**: HT 3.1, 3.3, 3.4, 3.6 p. 202-203. MO13 & MO14
9	10/13/03	HT				Continue HT Progress Check: HT §4.7	
		Exam				**MIDTERM EXAM** :-) 6:00pm - 8:00pm Meet in PS 054	
		HT				Continue HT Homework Checkpoint: HT §4.12	
		HT				Continue HT Progress Check: HT §5.4	**HW9**: HT 4.1, 4.2, 4.3, 4.4 p. 204-205. MO15 & MO16
10	10/20/03	HT				Continue HT Progress Check: HT §6.5	
		HT				Continue HT Homework Checkpoint: HT §7.2	SP5
		HT				Continue HT Progress Check: HT §7.5	**HW10**: HT 4.9, 6.3, 6.4 p. 206-209. MO17 & MO18
11	10/27/03	HT				Finish HT HT Catch-up Day Progress Check: HT §7.5 HT Project due 07 November 2003.	
		EC				Begin EC PBI - II, p. 383. Homework Checkpoint: EC §1.5	
		EC				Continue EC Progress Check: EC §1.10	**HW11**: HT 6.10, 6.13, 6.28, 7.1, 7.4, p. 210-216. MO19 & MO20
12	11/03/03	EC				Continue EC Progress Check: EC §2.1	
		EC				Continue EC Homework Checkpoint: EC §2.5	
		EC				Continue EC Progress Check: EC §2.7	HT Project due **HW12**: HT 7.13, 7.16, p. 217-219. EC 1.1, 1.2 p. 494.

Figure C.3. PBI Section Schedule - Fall 2003 - page 3

13	11/10/03	EC				Continue EC Progress Check: EC §3.4	
		AbS				Resume AbS Skip to §4.6, PBI - I, p. 346. Do ONLY §4.6; skip to §5.1. Homework Checkpoint: AbS §5.1	
		AbS				Continue AbS Progress Check: AbS §5.4	**HW13**: EC 1.3, 2.1, 2.2, 3.1, p. 494-496. AbS 4.2, p. 376.
14	11/17/02	AbS				Continue AbS Progress Check: AbS §5.7	
		AbS				Finish AbS We will not return to AbS! Homework Checkpoint: AbS §5.11	
		EC				Resume EC Progress Check: EC §3.9	**HW14**: AbS 5.1, 5.2, 5.3, 5.4, 5.5, p. 376-378.
15	11/24/02	EC				Continue EC Progress Check: EC §4.5 EC and AbS Project due 05 December 2003.	
						SKIP DAY - NO CLASS !!! :-) This day is skipped to make up for our Midterm Exam.	
						Thanksgiving Break - NO CLASS !!! :-)	
16	12/01/02	EC				Continue EC Progress Check: EC §4.9	
		EC				Continue EC Homework Checkpoint: EC §4.13	
		EC				Finish EC EC Catch-up Day Progress Check: EC §4.13 STEBI and MPEX survey completion. SPAMSS Survey.	EC & AbS Project Due. **HW15**: EC 3.4, 3.5, 4.4, 4.5, 4.7, p. 497-502.
17	**12/09/03**	Exam				**FINAL EXAM** :-) Tuesday, 09 December 2003 12:00pm - 1:50pm Meet in PS 054	
Schedule Revised through this date.							

Figure C.4. PBI Section Schedule - Fall 2003 - page 4

SP - a sun-plot, as per PBI - I, Experiment 1.3, p. 327.
MO - a moon observation, as per PBI - I, Experiment 2.7, p. 337.

Progress Check: Use these to plan appropriate progress through the material.
Homework Checkpoint: This section should be completed to ensure preparedness for the current Homework assignment.

Figure C.5. PBI Section Schedule - Fall 2003 - page 5

C.1.2 HBL

The schedule of HBL class activities for the fall 2003 semester is presented in this section.

PHYSICS 1313
Schedule Page
Fall 2003

Class Week #	Class Week Begins	Module	Day of the Week M	W	F	H B L Module and Topic (Class Activities)	Assignment Due on Date Listed (Homework Assignments)
1	08/18/03		■			Introduction to the course. STEBI and MPEX survey completion. Syllabus overview. Operational Definitions.	
		AbS		■		Begin AbS - learn data techniques. Altitude and Sun-Moon Angle Training. Moon Observation and Sun-Plot Fundamentals.	
		HBL			■	What is HBL? HBL Process overview and definitions. Process Training: Observation. Ice Observation Lab. Process Training: Explanation and Prediction. Modeling HBL - Ice Lab. Process Training: Fair Tests and Analysis. Conclusion of Ice Lab. Wrap-up Overview and Discussion. Modeling HBL - Candle Lab.	**HW1a**: Supplemental Homework Handout
2	08/25/03	LC	■			Begin LC. LC HBL Lab 1.	HBL Summary **HW1b**: LC 2.2, 2.4, p. 260-261.
		LC		■		Continue LC. LC HBL Lab 2. LC and AbS Homework Packet. Finalize Midterm Skip Day. Finalize Final Exam time.	LC HBL Lab 1 Worksheet
		AbS LC			■	Resume AbS. Review AbS data techniques. AbS HBL Lab 1.	**HW2**: LC 1.2, 2.5, 2.6, p. 259-262. MO1 & MO2

Figure C.6. HBL Section Schedule - Fall 2003 - page 1

						Resume LC. LC Lecture 1.	LC HBL Lab 2 Worksheet
3	09/01/03					**LABOR DAY** **University Holiday - NO CLASS !!!** :-)	
		LC				Continue LC. LC HBL Lab 3.	AbS HBL Lab 1 write-up SP1
		LC				Continue LC. LC HBL Lab 4.	LC HBL Lab 3 write-up **HW3**: LC 2.8, 2.9, 2.10, p. 263-264. AbS 1.2, p. 373. MO3 & MO4
4	09/08/03	LC				Continue LC. We will use paint today, so please dress appropriately. LC HBL Lab 5.	LC HBL Lab 4 write-up
		LC				Continue LC. LC HBL Lab 6.	LC HBL Lab 5 write-up SP2
		AbS				Resume AbS. AbS HBL Lab 2.	LC HBL Lab 6 write-up **HW4**: LC 2.11, 4.1, 4.2, p. 265-270. MO5 & MO6
5	09/15/03	LC				Resume LC. LC HBL Lab 7.	AbS HBL Lab 2 write-up
		LC				Continue LC. LC HBL Lab 8.	LC HBL Lab 7 write-up
		LC				Continue LC. LC HBL Lab 9.	LC HBL Lab 8 write-up **HW5**: LC 4.4, 6.1, 6.2, p. 270-272. AbS 2.2, p. 374. MO7 & MO8
6	09/22/03	LC				Finish LC. LC HBL Lab 10.	LC HBL Lab 9 write-up
		LC				LC wrap-up.	LC HBL Lab 10 write-up

Figure C.7. HBL Section Schedule - Fall 2003 - page 2

						All LC HBL Worksheet files due. LC Lecture 1.	All LC HBL Worksheet files due. SP3
		HT				Begin HT. HT HBL Lab 1. HT Homework Packet.	**HW6**: LC 7.1, 7.2, 7.3, p. 272-273. MO9 & MO10
7	09/29/03					**Fall Break - NO CLASS !!!** :-)	
		HT				**Reminder: OSU treats today as MONDAY.** Continue HT HT HBL Lab 2.	HT HBL Lab 1 write-up
		HT				Continue HT HT HBL Lab 3.	HT HBL Lab 2 write-up **HW7**: LC 7.4, p. 274. OD's: Mass, Temperature, Volume HT 1.2, p. 202. MO11 & MO12
8	10/06/03	HT				Continue HT HT HBL Lab 4.	HT HBL Lab 3 write-up
		HT				Continue HT HT HBL Lab 5.	HT HBL Lab 4 write-up SP4
		HT				Continue HT HT Lecture 1.	HT HBL Lab 5 write-up **HW8**: HT 3.1, 3.3, 3.4, 3.6 p. 202-203. MO13 & MO14
9	10/13/03	HT				Continue HT HT HBL Lab 6.	
		Exam				**MIDTERM EXAM** :-) 6:00pm - 8:00pm Meet in PS 054	
		HT				Continue HT HT HBL Lab 7.	HT HBL Lab 6 write-up
		HT				Continue HT HT Lecture 2.	HT HBL Lab 7 write-up **HW9**: HT 4.1, 4.2, 4.3, 4.4 p. 204.

Figure C.8. HBL Section Schedule - Fall 2003 - page 3

							MO15 & MO16
10	10/20/03					Continue HT HT HBL Lab 8.	
		HT				Continue HT HT HBL Lab 9.	HT HBL Lab 8 write-up SP5
		HT				Continue HT HT HBL Lab 10.	HT HBL Lab 9 write-up **HW10**: HT 4.9, 6.3, 6.4 p. 206-209. MO17 & MO18
11	10/27/03	HT				Finish HT HT Lecture 3.	HT HBL Lab 10 write-up
		EC				Begin EC EC HBL Lab 1. EC Homework Packet.	
		EC				Continue EC EC HBL Lab 2.	EC HBL Lab 1 write-up **HW11**: HT 6.10, 6.13, 6.28, 7.1, 7.4, p. 210-216. MO19 & MO20
12	11/03/03	EC				Continue EC EC HBL Lab 3.	EC HBL Lab 2 write-up
		EC				Continue EC EC Lecture 1.	EC HBL Lab 3 write-up
		EC				Continue EC EC HBL Lab 4.	**HW12**: HT 7.13, 7.16, p. 217-219. EC 1.1, 1.2 p. 494.
13	11/10/03	EC				Continue EC EC HBL Lab 5.	EC HBL Lab 4 write-up
		AbS				Resume AbS Cosmological Model Activity.	EC HBL Lab 5 write-up
		AbS				Continue AbS Moon Data Handout AbS Moon Data Analysis.	Cosmological Activity Questions **HW13**: EC 1.3, 2.1, 2.2, 3.1, p. 494-496. AbS 4.2, p. 376.

Figure C.9. HBL Section Schedule - Fall 2003 - page 4

14	11/17/03	AbS				Continue AbS AbS HBL Lab 3.	Moon Data Analysis Questions
		AbS				Finish AbS AbS Lecture 1.	AbS HBL Lab 3 write-up
		EC				Resume EC EC HBL Lab 6.	**HW14**: AbS 5.1, 5.2, 5.3, 5.4, 5.5, p. 376-378.
15	11/24/02	EC				Continue EC EC HBL Lab 7.	EC HBL Lab 6 write-up
						SKIP DAY - NO CLASS !!! :-) This day is skipped to make up for our Midterm Exam.	
						Thanksgiving Break - NO CLASS !!! :-)	
16	12/01/03	EC				Finish EC EC Lecture 2.	EC HBL Lab 7 write-up
						Final Course activity.	
						Finish Course Final Wrap-up. All HT, AbS, and EC HBL Worksheet files due. STEBI and MPEX survey completion. SPAMSS Survey.	**HW15**: EC 3.4, 3.5, 4.4, 4.5, 4.7, p. 497-502. All HT, AbS, and EC HBL Worksheet files due.
17	**12/09/03**	Exam				**FINAL EXAM** :-) Tuesday, 09 December 2003 12:00pm - 1:50pm Meet in PS 054	
Schedule Revised through this date.							

SP - a sun-plot.
MO - a moon observation.

Figure C.10. HBL Section Schedule - Fall 2003 - page 5

C.2 Supplemental Homework

The Supplemental Homework activity appears in the following Figure.

C.3 HBL Laboratory Worksheet

The HBL Laboratory Worksheet appears in the following Figures.

Supplemental Homework
Physics 1313
Fall 2003

In the following problems, one may assume that the contents of the syllabus are available to the person grading the answers provided. Be sure to explain how each calculation was performed in the typewritten responses to each question. Remember: Mathematics without written explanation is worth **zero** credit (as always!). This handout contains four problems, which should be submitted individually. It may be helpful to refer to the Homework page of the site for homework problem guidelines.

1. Many students are concerned about what scores they need to have to achieve a particular grade. Despite Chuck's assurances to the contrary, some students do not believe the ease with which they may earn a "B" course grade in Physics 1313. Assuming all five components of the course are each worth 4 "points", calculate the minimum number of "points" necessary to get every letter grade.

2. Let's pretend that Chuck, a not-particularly well-motivated student, decides he doesn't want to take the Final Exam (he desperately needs to go fishing that day). Unfortunately for him, this is a continuation of the pattern he established on the Midterm Exam (that he also failed to take). Is it possible for him to earn a passing grade in this course? Please explain your answer in detail.

Operational Definitions (OD's) are organized around having discrete steps, or actions, performed in a particular order. Following those steps or actions allows an ignorant user to obtain the same understanding of the term as the author. Provide the steps or actions someone would have to follow to understand each of the following two "special" terms. In this exercise, no special-purpose equipment, such as a level, is available: anyone following the provided definitions must be able to do so using only commonly available materials.

HINT #1: Don't forget that obtaining any equipment needed is a step…!
HINT #2: If a term is defined operationally, can it be used as a "building block" in another OD?
HINT #3: Be SURE to show STEPS in the OD's! (It may be helpful to label them…)

In the following two problems, OD's are to be provided for two terms. It is not necessary to support how the OD was obtained, nor how it works. Non-Operational Definitions will receive **zero** credit, and an invitation to try again for reduced credit!

3. Operationally define **Vertical**. Please include specific steps in your definition.

4. Operationally define **Horizontal**. Please include specific steps in your definition.

Figure C.11. Supplemental Homework Activity

HBL Lab Worksheet

Name: **Lab Name:** **Lab Score: ________**

Use proper written English and limit your answers to two pages. Attach any supplemental data.

_____ Observations: What details of the system captured your interest? Provide (at least) your 10 best original, insightful, nontrivial, and relevant observations (with context) that pertain directly to your investigations. Observations may not come from the Initiating Event. Inclusion of trivial observations will likely cause poor overall Lab grades.

1.	
2.	
3.	
4.	
5.	
6.	
7.	
8.	
9.	
10.	

_____ Observation to be Explored: Choose one (or more) of the observations above that your investigations focus upon and place it here. The remainder of this lab report will regard only this observation, which should not be previously understood.

_____ Hypothesis: Provide a rational and testable explanation or reason for the system's behavior. Insure that your hypothesis adequately explains your Observation to be Explored above.

_____ Prediction: Consider changing the situation above (or one related by the hypothesis) in a NEW way. How *should* the system react if this aspect were altered? Predictions must be related to your hypothesis and unrelated to observations above.

What is to be altered?	
If the hypothesis is **true**, what should happen?	
How does your hypothesis explain the true result?	
If the hypothesis is **false**, what should happen?	
What is the basis for this prediction?	

_____ Experiment: Using the situation above, create a 'fair test' using the available equipment that will evaluate your predictions a minimum of 3 times. Include specific steps in your experimental outline, indicating appropriate variable control. This experiment must be fundamentally NEW; it cannot be something previously observed or performed!

Variable(s) changed:	
Variable(s) controlled:	

Figure C.12. HBL Laboratory Worksheet - page 1

_____ **Experimental Results:** **Perform the experiment previously outlined. What happened when the experiment was performed? Report only what actually occurred here; interpretation of the results will be performed below. Be specific when reporting outcomes – this is an excellent place to report numerical data or data tables!**

_____ **Analysis of Results:** **Interpret your experimental results and assign meaning to them by answering the following four questions. Include specific reasons for the comments made in each question.**

Are the experimental results consistent with the prediction you made?
Which specific experimental results support or remove support from your prediction?
Do the experimental results support or remove support from your hypothesis?
Which specific experimental results support or remove support from your hypothesis?

_____ **Reformulation:** **Consider the analysis of your experimental results. Did your hypothesis adequately explain the system's behavior? If the hypothesis was unsupported or partially supported, it must be revised.**

- **If your hypothesis was supported, discuss how the experimental results support your hypothesis.**
- **Otherwise, provide a reformulated hypothesis that explains the system's behavior in light of the new results.**

_____ **Communication:** **What new knowledge was gained as a result of your experiment? Be specific!**

Figure C.13. HBL Laboratory Worksheet - page 2

C.4 Light and Color

All Light and Color HBL material created for Physics 1313 is presented in this section.

C.4.1 HBL Laboratories

All 10 HBL Light and Color Laboratories appear in the following Figures.

Physics 1313
Experiment LC 1 Outline

<table>
<tr><th colspan="4">LC 1 - Reflecting Color</th></tr>
<tr><td>Background</td><td colspan="3">The 'stuff' light encounters as it travels is commonly referred to as the medium. Sometimes it is referred to as 'material', but it should be understood that this indicates the actual substance (like water, glass, or air), not that the substance is solid.

Light may interact with a medium in one of four fundamental ways: it may propagate, be reflected, refracted, or absorbed.

Propagation indicates that light simply travels through a transparent medium. This is what happens when light travels through water or air. Light that makes it through the medium is said to be transmitted.

Reflection occurs when the light encounters the surface of a material different from the one it is traveling through. The light changes direction as a result of the interaction with the new surface. This is what happens when light hits a mirror or when a glass looks 'shiny'. Note that the light <u>does not</u> actually enter the material it reflects off.

Refraction is the change in direction of light's travel (bending) as it propagates from one material <u>into</u> another. When looking at a straight drinking straw placed in a glass of water, the straw no longer appears to be straight. Lenses in eyeglasses utilize this phenomenon. Refraction can occur within a single material, provided the material's properties change from place to place - this may be seen when observing mirages.

Absorption is the loss of light as it propagates through the medium. If the light were to travel through enough of the material, it would be completely removed. This is seen when looking at a light through smoke - when the smoke is 'thin', the light is bright; if there is much smoke the light is quite dim. Sunglasses and welding visors use this effect.

Sometimes more than one of these things happen to the light simultaneously - for instance, light must propagate through a medium for it to be absorbed. Light may also be refracted as it propagates, giving rise to twinkling stars and mirages.</td></tr>
<tr><td rowspan="2">Equipment</td><td>flashlight</td><td>white paper or surface (screen)</td><td>multiple colored construction paper sheets, including black</td></tr>
<tr><td>additional materials varying in texture and color, such as aluminum foil, plastic, velvet, or sandpaper</td><td>tape</td><td></td></tr>
<tr><td>Experimental Setup</td><td colspan="3">These experiments must be performed in a darkened room.

Place a substance (paper, plastic, velvet, etc) on a tabletop. This substance is called the object.</td></tr>
</table>

Figure C.14. HBL Laboratory LC 1 - page 1

	Shine a flashlight downwards at an angle onto the object. Light reflected from the surface is displayed on a *screen* - another, usually white, piece of paper held on the opposite side of the flashlight and above the object. The screen is usually inclined with the top towards the object to better collect the reflected light.
Initiating Event	Shine the flashlight onto a white paper object, displaying the reflected light on a white paper screen. Invite discussion and observations. Repeat the experiment, using a red construction paper object and white screen. Invite discussion and observations. Repeat the experiment, using a green construction paper object and white screen. Invite discussion and observations.
Required Submissions	Students work in pairs, collaborating on a **single** experiment. At least twenty observations from each student pair are required. Although the experiments will be identical, each student will submit their own original HBL worksheet. This is the only collaborative experiment in the course.
That's odd...	The black velvet actually looks *deep red* when placed over the lit flashlight. Although there is a bright spot at the center of the flashlight beam, there is not a bright spot of reflected color on the screen. No colored reflection shows on a black screen.
Food for Thought	How does light travel? Why does the angle the flashlight make with respect to the object not seem to change what is displayed on the screen? Did any color 'mixing' occur when differently colored objects and screens were used?

Figure C.15. HBL Laboratory LC 1 - page 2

Physics 1313
Experiment LC 2 Outline

<table>
<tr><th colspan="4">LC 2 - Masked Lights 1</th></tr>
<tr><td>Background</td><td colspan="3">Light travels along a straight path and only changes direction when it interacts with a medium or a surface. If the medium is not the same everywhere, the propagating light may be refracted, altering its direction of travel. This gives rise to some 'distortions' in the images seen through old windowpanes and the 'twinkling' of stars. Otherwise, light rays are straight.

Light has a more curious side to its nature - although it travels along straight paths, under certain circumstances it may be deviated (bent) by a small amount as it passes the surface of an object or goes through an opening in a solid object. This change in the direction of a light ray due to its interaction with a surface or opening is called diffraction. Diffraction effects are usually quite small, but some situations can magnify them. Just as water waves passing a point of land sticking out into a larger body of water will bend around the land, light will bend around the edges of an opening in a solid object and cause its image to become less distinct. The farther the object is from the reflective surface showing the image, the more pronounced the diffractive effects.

To actually see diffraction at work, you may perform an experiment. Using a sharp pin, create a small hole no more than 0.5 mm in diameter in a piece of heavy paper. Hold this paper up to a light and observe the hole from a variety of distances from your eye. At about 10 cm - 15 cm from your eye, you should see a faint pattern inside the hole that looks like smaller circles or honeycomb cells. This pattern results from the light diffracting (bending) around the edges of the hole (and is actually made into a light-and-dark pattern by interference - an interaction of several light rays that can make the light either brighter or darker). Another method of seeing diffractive effects is illustrated in LC 4 - Shadows 1.</td></tr>
<tr><td rowspan="2">Equipment</td><td>Battery with holder</td><td>single small bulb with holder and connecting wires</td><td>white paper or surface (screen)</td></tr>
<tr><td>scissors</td><td>tape</td><td>multiple colored construction paper sheets, including black</td></tr>
<tr><td>Experimental Setup</td><td colspan="3">These experiments must be performed in a darkened room.

Using the scissors, cut a neat hole of distinct shape (circle, triangle, rectangle, etc.) in a piece of construction paper. This paper with a hole is called the mask. Initially, the mask should have a hole approximately 1 cm in size, although later experiments may investigate changes in the image due to altering the mask. Connect a single bulb to a battery such that it lights up. Arrange the apparatus so the light the shines through the mask onto a white screen. Notice that the light is confined to well-defined region on the screen. This shape is called the image.</td></tr>
<tr><td>Initiating Event</td><td colspan="3">Shine the light through the mask onto the screen. Invite discussion and observations.

Move the light left and right and observe the image on the screen. Invite discussion and observations.</td></tr>
</table>

Figure C.16. HBL Laboratory LC 2 - page 1

	Move the light closer to the mask and observe the image on the screen. Invite discussion and observations.
Required Submissions	Students work in pairs, collaborating on an individual experiment for **each** student. At least twenty observations from each student pair are required. An original, completed HBL worksheet is required from each student.
That's odd...	The image is almost always larger than the hole in the mask. The image is not always distinct: sometimes it is sharp-edged, sometimes blurry. At large light-mask distances, the image begins to take the shape of the bulb.
Food for Thought	There seems to be some inversion involved in creating the image - is *everything* inverted? The image seems to change size in a regular manner - would geometry help in determining a relationship between the variables and the image size?

Figure C.17. HBL Laboratory LC 2 - page 2

Physics 1313
Experiment LC 3 Outline

LC 3 - Masked Lights 2			
Background	When two or more sketches are displayed on the same drawing one on top of the other, they are said to be **superposed**. **Superposition** may also be used to mean several things being done at the same time. For instance, if an airplane is flying due north while experiencing a crosswind blowing towards the east, the path of the airplane over the ground will be given by the superposition of traveling in both directions. This shows that the plane will travel in a northeasterly direction. A similar effect may be seen if both the faucet and drain in a bathtub are opened: the tub may fill faster than it can drain, it may drain at the same rate as it is filled, or it may drain faster than water is added. Either way, the amount of water in the tub at any time is given by the action of both influences at the same time.		
Equipment	several 110V light holders	2 or 3 differently shaped light bulbs (incandescent, long filament, etc.)	white paper or surface (screen)
	scissors	tape	multiple colored construction paper sheets, including black
Experimental Setup	**These experiments must be performed in a darkened room.** Using the scissors, create a mask by cutting a neat hole of distinct shape (circle, triangle, rectangle, etc.) in a piece of construction paper. Initially, the mask should have a hole approximately 1 cm in size, although later experiments may investigate changes in the image due to altering the mask. Connect two light sources such that they light. Arrange the apparatus so the light the shines through the mask onto a white screen. Notice that the light causes an image on the screen.		
Initiating Event	Illuminate the mask with a single long filament bulb. Observe the image on the screen. Invite discussion and observations. Arrange two long filament bulbs in an "L" shape. Observe the image on the screen. Invite discussion and observations.		
Required Submissions	Students work in pairs, collaborating on an individual experiment for each student. At least twenty observations from each student pair are required. An original, completed HBL worksheet is required from each student.		
That's odd...	Covering a portion of the light source (or hole in the mask) does not cause similar image changes. The image is not always distinct: sometimes it is sharp-edged, sometimes blurry, but this is especially true with long filament bulbs. Long filament bulb images may be caused to 'jump' between two different positions.		
Food for Thought	Are those shapes **really** "three-dimensional"? There seems to be some inversion involved in creating the image - is *everything* inverted? The image seems to change size in a regular manner - would geometry help in determining a		

Figure C.18. HBL Laboratory LC 3 - page 1

Physics 1313
Experiment LC 4 Outline

LC 4 - Shadows 1			
Background	When light encounters an **opaque** medium (one that does not transmit light) it is absorbed, reflected, or simply blocked. Only light rays not encountering the opaque medium will continue past the obstruction. Thus, solid objects that are not transparent cast shadows when exposed to light. **Shadows** are caused by a *reduction* in the amount of light striking a screen or other reflective surface. The difference in the amount of light on the reflective surface is perceived as the place receiving less light being 'darker' in comparison to the well-lit region. This may give a way to understand how the moon can cause shadows of objects at night. Diffraction can occur either in situations involving a mask with a hole in it, or in situations where solid objects cast shadows. However, diffractive effects should *not* be confused with the 'blurring' caused by light rays from an extended source. To actually *see* diffraction at work, you may perform an experiment. In a very dark room, light a single incandescent bulb and place it a distance greater than 2 m from you. Observe the shadow cast by a solid opaque object onto a white screen when the object is located at various distances from the screen. At a distance of approximately 5 cm, the shadow of the object should be quite distinct, but when the object is brought closer to the screen the shadow becomes appreciably *less* distinct. This results from the light diffracting (bending) around the edges of the object.		
Equipment	several 110V light holders	2 or 3 differently shaped light bulbs (incandescent, long filament, etc.)	Batteries with holders
	small bulbs with holders and connecting wires	string	small amount of modeling clay
	medium-sized, open-topped cardboard box	tape	white paper or surface (screen)
Experimental Setup	**These experiments must be performed in a darkened room.** Using the clay, create a distinct shape (circle, triangle, rectangle, etc.) approximately 2 cm in size and attach it to one end of the string. Place the box on its longest side with the open side perpendicular to the tabletop. Tape a white screen in place inside the box on the vertical surface opposite the opening. Attach the free end of the string to the top of the box such that the clay shape is suspended in the center of the opening. This clay, string, and box combination is called a *shadow box*. Connect one or more light sources such that they light. Arrange the apparatus so the light the shines through the opening of the shadow box past the clay shape and onto the screen. Notice that light is spread more-or-less uniformly over the screen except where darkness is confined to one or more well-defined region(s) on the screen; this dark shape is called the *shadow*.		

Figure C.19. HBL Laboratory LC 4 - page 1

Initiating Event	Shape the clay into a roughly 30-60-90 degree triangular shape with the 30 degree vertex pointing upwards when suspended by the string. Illuminate the clay with a single small bulb. Observe the shadow on the screen. Invite discussion and observations. Move the small bulb to the left. Observe the shadow on the screen. Move the small bulb away from the clay triangle. Observe the shadow on the screen. Invite discussion and observations. Arrange two long filament bulbs in an "L" shape and illuminate the clay. Observe the shadow on the screen. Invite discussion and observations.
Required Submissions	Students work in pairs, collaborating on an individual experiment for each student. At least twenty observations from each student pair are required. An original, completed HBL worksheet is required from each student.
That's odd...	The shadow always seems to be larger than the clay object. The image is not always distinct: sometimes it is sharp-edged, sometimes blurry, but this is especially true with long filament bulbs. Images formed by a single long filament bulb may be caused to have at least two distinctly different shadow 'darknesses'.
Food for Thought	Are those shapes **really** "three-dimensional"? There seems to be some inversion involved in creating the shadow - is *everything* inverted? The shadow seems to change size in a regular manner - would geometry help in determining a relationship between the variables and the shadow size and orientation?

Figure C.20. HBL Laboratory LC 4 - page 2

Physics 1313
Experiment LC 5 Outline

LC 5 - Mixing Pigments	
Background	The world would be much less rich without color. The terminology used to talk about color is vast and sometimes confusing, but three major terms are relatively accessible to persons wishing to discuss color. **Hue** is the general color we are referring to, such as red, green, or orange. Think of hue as the color being discussed. **Value** refers to the relative lightness or darkness of a particular hue. For instance, "sky blue" and "navy blue" are both blue in hue, but one is light and the other is dark in value. **Saturation** refers to the *brightness* of a particular color as compared to the brightness of the same color when generated by a prism. Value and saturation are easily confused, but remember that saturation represents purity of a color, while value indicates lightness or darkness of that hue. Colors can also be separated into groups according to the following grouping definitions: **Primary** colors of pigment are those that cannot be made using a combination of other colors. A complete set of primary colors allows creation of all other colors. Combinations of primary pigments result in **secondary** colors. **Complementary** colors are *pairs* of colors: pick a primary color and then identify the secondary color having none of the chosen primary. Human vision uses different structures (named for their shape) to detect light. **Cones** detect color information and are sensitive to one of three colors of light: reddish, bluish, or greenish. **Rods** confer information regarding black and white. The eye detects the presence of colors using only the three different color receptors on cones; all other colors are 'seen' by stimulating those receptors in combination with one another while the brain interprets this simultaneous stimulation as a distinct color. As an optical device that is adapted to work best in its normal environment, our eyes are most sensitive to yellows and greens, and least sensitive to blues and reds. This may indicate a compelling reason to change the colors of emergency vehicles such as fire trucks: red grabs the attention, but who could possibly miss one of those yellow-green vehicles? The locations of the cones and rods within the eye are different: cones are concentrated near the center of the retina in a place called the **fovea**, and are ringed by the rods. This explains why we are best able to see things at night when we do not look directly at them - looking directly at the object means the light from it falls on the fovea, where the cones are. Being insensitive to low light levels, cones do not work well at all in relatively dark environments. Looking to the side of an object causes light from it to encounter the rods in the eye, allowing it to be seen. One of the defects in human vision is commonly called **colorblindness**, indicating the person either has a reduced ability to perceive a particular color or that they cannot see the color at all. Colorblindness is named for the colors the person has difficulty distinguishing and comes in several varieties, including red-green (most common) and yellow-blue (very rare). Colorblindness affects only a small fraction of the population (5% - 8%) and is much more likely in men than

Figure C.21. HBL Laboratory LC 5 - page 1

	women. It is thought that colorblindness has a few causes: differences in pigments used to detect light in the cones, absence of those pigments in cones, nerve damage causing incorrect stimuli to be sent to the brain, or problems in the brain itself causing misinterpretation of color information.		
Equipment	acrylic paint: magenta, cyan, yellow, red, blue, green (no white or black)	2 or 3 paintbrushes	white paper
	pyrex beaker	paint palette	water
	paper towels		
Experimental Setup	**Students should be informed prior to this lab that they will be using paint and should dress appropriately.** **These experiments must be performed in a well-lit room.** Obtain portions of paint on the palette. Mix paint of various colors on the white paper, noting approximate proportions and colors used.		
Initiating Event	Mix yellow and blue paint. Invite discussion and observations. Mix yellow and magenta paint. Invite discussion and observations.		
Required Submissions	Students work in pairs, collaborating on an individual experiment for each student. At least twenty observations from each student pair are required. An original, completed HBL worksheet is required from each student.		
That's odd...	Proportions of the paint used seem to be quite important in determining the final color. The color of the water used to wash the brushes changes in interesting ways. Paint placed on glossy paper would rather stick to the brush than the paper and is difficult to mix. Some 'colors' may be quite difficult to make....		
Food for Thought	Which group of colors is **really** primary? What changes as the paint 'dries'?		

Figure C.22. HBL Laboratory LC 5 - page 2

Physics 1313
LC 6 Experiment Outline

<table>
<tr><th colspan="2">LC 6 - Markers and Chromatography</th></tr>
<tr><td>Background</td><td>Fluid (liquid) media have many interesting properties.

Solid substances, when placed in liquids, may sometimes seem to <u>disappear</u> 'into' the liquid. This is often apparent when adding sugar to tea, or salt to water when cooking pasta. Solids that show this behavior are said to be soluble in the liquid, and the degree or extent to which they become incorporated into the liquid is termed solubility. The liquid capable of dissolving a solid is termed a solvent. Not all solids are soluble in a given liquid, nor are all liquids capable of dissolving a particular solid. This is seen when making brownies - no matter how one tries, sugar will not dissolve into oil.

Other liquids and even gases may be soluble in a given fluid. Bubbles of carbon dioxide gas are soluble in water (forming 'sodas'), and are usually seen to come from nowhere and 'bubble' into the soda. Fluids that are soluble in one another may be mixed, and are termed miscible, while fluids that are not are called immiscible. Alcohol and water are miscible, while oil and water are immiscible.

Anytime one substance is incorporated within another, portions of the mixture redistribute themselves in such a way that they become uniformly distributed. For example: smoke in a room will tend to move to all parts of the air in the room, a strong smell like ammonia never stays in just one small area - it travels (and may be smelt) throughout the air nearby, all of a saltwater solution tastes equally salty, and every part of a glass of soda has bubbles. This movement of one substance within another is called diffusion and always causes high concentrations of one substance to be redistributed to more uniform lower concentrations throughout another substance.

Fluids usually 'like' to have all portions in contact with the bulk (majority) of the fluid. This cohesion, or affinity of a fluid for itself, accounts for how a fluid forms into drops or how it is shaped when it touches the sides of a container. Any part of a fluid that is on the surface feels 'pulled' into the bulk of the fluid by this cohesion, and results in the surface of the water acting like a sheet that has been pulled taught or the surface of a trampoline. The measure of this 'pull' on the surface of a fluid is called surface tension. Just as a child dimples the surface of a trampoline but does not fall through the surface, some insects like water spiders take advantage of surface tension to walk and skate across the surface of pools of water.

When a liquid touches a solid, some of the fluid may 'stick' to the solid surface. This affinity of a fluid for other materials is called adhesion. Highly cohesive fluids would rather stick to themselves rather than another substance, resulting in surfaces that curve away from the material where the two touch. Highly adhesive fluids would rather stick to another substance rather than themselves, resulting in surfaces that curve towards the material where the two touch.

The 'thickness' of a liquid is called viscosity - high viscosity fluids like syrup are difficult to pour, while low viscosity fluids like gasoline are easy to pour.</td></tr>
</table>

Figure C.23. HBL Laboratory LC 6 - page 1

<table>
<tr><td></td><td colspan="3">Paper Chromatography is the process of using a liquid solvent to 'spread out' the components of a mixture onto a paper medium.

Many different aspects of fluids may interact simultaneously to provide interesting effects. Capillary Action is a good illustration of this: a fluid may utilize both cohesion and adhesion to allow it to 'climb' through small cracks or over surfaces, while viscosity serves as a limiting factor to this behavior.

One of the more interesting (and strange) phenomena in nature is that some solids exhibit fluid properties - have you ever tried pouring wheat flour? Maybe this is a solid flour mixture with air....</td></tr>
<tr><td rowspan="2">Equipment</td><td>water-soluble markers (Crayola, etc)</td><td>paper towels</td><td>scissors</td></tr>
<tr><td>clear watertight containers, 7 cm diameter or larger</td><td>water</td><td></td></tr>
<tr><td>Experimental Setup</td><td colspan="3">Fill a clear watertight container with water to a depth of approximately 3 cm. Cut paper towels into strips 2 cm - 3 cm wide. Place differently colored 1 mm - 3 mm wide marker stripes across the strip about 3 cm from one end. The end of the strips nearest the colored stripe will be placed in the water. Insure the stripe of color is clearly above the surface.</td></tr>
<tr><td>Initiating Event</td><td colspan="3">Place the ends of three differently colored strips into the water, leaving the colored stripe above the surface of the water. The strips may be conveniently held in place by creasing them at the top of the container, leaving the ends farthest from the colored strip draped outside the container.

Invite discussion and observations. Remind students that some observations are made over a period of time, while others are best made by comparing similar situations.</td></tr>
<tr><td>Required Submissions</td><td colspan="3">Students work in groups, collaborating on every member's experiments. Each student should complete his own unrelated lab activity. At least twenty observations from each student are required. An original, completed HBL worksheet is required from each student.</td></tr>
<tr><td>That's odd...</td><td colspan="3">Water 'climbs' the paper towel strips, but doesn't 'climb' out of the container on its own.
Colored marker sections placed underwater after getting wet give off 'filaments' of color - but those 'filaments' change with time.
When the paper towel section is wet and is touching the side of the container, it seems to get 'glued' in place.</td></tr>
<tr><td>Food for Thought</td><td colspan="3">What ARE the primary colors of marker pigment, anyway?
The water that soaks into the paper towel - where does it come from?</td></tr>
</table>

Figure C.24. HBL Laboratory LC 6 - page 2

Physics 1313
Experiment LC 7 Outline

LC 7 - Mixing Light			
Background	Recall that colors can be separated into groups according to the following grouping definitions: **Primary** colors are those that cannot be made using a combination of other colors. A complete set of primary colors allows creation of all other colors. Combinations of primary colors result in **secondary** colors. **Complementary** colors are *pairs* of colors: pick a primary color and then identify the secondary color having none of the chosen primary.		
Equipment **Method 1**	colored transparency acetates: magenta, cyan, yellow, red, blue, green	2 or 3 flashlights	white paper
Equipment **Method 2**	colored transparency acetates: magenta, cyan, yellow, red, blue, green	110V lamp holder with incandescent bulb (60W or less)	white paper
	scissors	tape	medium-sized, open-topped cardboard box
	2 small mirrors	4" x 6" index cards	
Experimental Setup	**These experiments must be performed in a darkened room.** **Note: The acetates can be permanently deformed by force or by high temperatures. Please take care to use the acetates without crinkling or heating them!** This experiment may be performed in one of two ways. **Method 1** (easiest) Place a single colored acetate over the lit end of a flashlight, causing the colored light to be shone onto a white surface. Repeat this with a second flashlight and a differently colored acetate, *overlapping* the colored flashlight beams. **Method 2** (more challenging) Using the box, scissors, tape, and an index card, create a *light box* that will allow light from inside the box to form two beams of light that fall on the tabletop and form two well-lit overlapping 'V'-shapes (similar in shape to a "W"). The beams should have a distinct and well-lit overlapping region; the light's position within the box may have to be adjusted to cause this to happen. This may be done by cutting a hole in the box and covering the hole with a mask. Take care to make sure the mask will fully cover the hole in the box. The slits in the index card should be approximately 0.5 cm to 1 cm wide and 4 cm long. The light box should then be placed over the lit		

Figure C.25. HBL Laboratory LC 7 - page 1

	light bulb and adjusted so the beams are formed. Please insure the bulb does not touch the box - the box may get too hot. Place a piece of white paper on the tabletop so the light beams fall on this paper screen. Place one acetate over a single rectangular opening and a second, differently colored, acetate over the second opening. The colored regions produced by the acetates should overlap on the screen. Should the regions not overlap sufficiently, mirrors may be used to reflect one colored region onto the other.
Initiating Event	Indicate the intention to have blue light overlap yellow light, and invite *predictions*. Cause blue light to overlap yellow light. Invite discussion and observations. Indicate the intention to have red light overlap green light, and invite *predictions*. Cause red light to overlap green light. Invite discussion and observations.
Required Submissions	Students work in pairs, collaborating on an individual experiment for each student. At least twenty observations from each student pair are required. An original, completed HBL worksheet is required from each student.
That's odd...	Light from individual sources and overlapped transparencies seem to work differently. When a flashlight illuminates an acetate placed on a white surface and a colored surface, strange things happen. Some 'colors' may be quite difficult to make....
Food for Thought	Which group of colors is **really** primary? How can the proportions of colors used in mixing be changed? Do the transparencies *add* their color to the light or do they act as 'filters'?

Figure C.26. HBL Laboratory LC 7 - page 2

Physics 1313
Experiment LC 8 Outline

LC 8 - Prisms and Acetates	
Background	Recall that light refracts (changes direction) as it propagates from one material into another. We understand this change in direction to be dependent upon the speed the light has inside the material. Some transparent materials allow light to propogate through them more quickly than others. Which way the light bends, and how much it bends, is determined by the material the light is initially in and by which material it will enter. To some extent, it may also depend upon the *color* of the light! This phenomenon may give rise to interesting effects, including the ability of a prism to display a full 'rainbow' of color - a **spectrum**. Every transparent material bends light by an amount characterized by a property called **index of refraction**. The index of refraction of a material (or index) is a number, typically between 1.00 and 2.42, that indicates how the light's speed is altered as it propagates through the material. High index materials allow light to move more slowly through them than low index materials. Typical index of refraction values are: 1.0004 for air, 1.33 for water, 1.52 for glass, and 2.42 for diamond. These numbers are not something a person needs to 'know', but are only given to illustrate the differences between materials. If two differing materials are placed in contact with one another, we call the place where their surfaces touch the **interface**. We can also define a unique direction with regard to the interface. It is customary to define the direction perpendicular to the plane of the interface as the **normal** direction. Normal, in this mathematical context, simply means perpendicular. If light is traveling through a low index material and then encounters a different material with a higher index of refraction, it will slow down as it enters the new material. This slowing down causes the light to bend *towards* the normal on the other side of the interface. This is easiest to see if one thinks of the light crossing the surface without changing direction. Then, because of the change in the speed of the light's travel, the light in the *new* material is shifted to an angle closer (towards) the normal. If light is traveling through a high index material and then encounters a different material with a lower index of refraction, it will speed up as it enters the new material. This speeding up causes the light to bend *away from* the normal on the other side of the interface. This story is complicated a bit by noting that each different color may be bent by a different amount by the same material, even if it is allowed to enter the material in a uniform manner. This means that different colors of light will be 'spread out' in traveling through a material. This separation of colors by a material is called **dispersion**. This accounts for the ability of a prism to 'spread light out' according to its color. The mathematical summary of this situation is called **Snell's Law** in honor of the scientist who formally codified the relationship between the materials and the directions of the incoming (**incident**) and refracted light rays.

Figure C.27. HBL Laboratory LC 8 - page 1

Equipment	colored transparency acetates: magenta, cyan, yellow, red, blue, green	flashlight	white paper
	prisms or diffraction gratings		
Experimental Setup	**These experiments must be performed in a darkened room.** **Note: The acetates can be permanently deformed by force or by high temperatures. Please take care to use the acetates without crinkling or heating them!** Using the flashlight and prism or diffraction grating, cause a distinct spectrum to be displayed on a white screen. It may be necessary to experiment with the apparatus to get a good spectrum, so don't get discouraged.		
Initiating Event	Show the spectrum on the screen. Invite discussion and observations. Indicate the intention to have a red acetate placed between the light and prism or diffraction grating, and invite *predictions*. Cause red light to enter the prism or diffraction grating. Invite discussion and observations. Remove the red acetate. Indicate the intention to place a blue acetate between the prism or diffraction grating and the screen. Invite *predictions*. Place a blue acetate between the prism or diffraction grating and screen. Invite discussion and observations.		
Required Submissions	Students work in pairs, collaborating on an individual experiment for each student. At least twenty observations from each student pair are required. An original, completed HBL worksheet is required from each student.		
That's odd...	Light seems to bend twice as it goes through the prism. Where is magenta? How in the world can one prism and one flashlight make *two* spectra at the same time?		
Food for Thought	Are all colors present in the spectrum? How **does** an acetate work, anyway? Rainbows seem to have these colors and in this order, but is red or blue on the outside of the arch?		

Figure C.28. HBL Laboratory LC 8 - page 2

Physics 1313
Experiment LC 9 Outline

LC 9 - Shadows 2			
Background	Recall that **shadows** are caused by a *reduction* in the amount of light striking a screen or other reflective surface. The difference in the amount of light on the reflective surface is perceived as the place receiving less light being 'darker' in comparison to the well-lit region.		
Equipment	several 110V light holders with incandescent bulbs	colored acetates: magenta, cyan, yellow, red, blue, green	Batteries with holders
	small bulbs with holders and connecting wires	medium-sized, open-topped cardboard box	small amount of modeling clay
	string	tape	white paper or surface (screen)
Experimental Setup	**These experiments must be performed in a darkened room.** **Note: The acetates can be permanently deformed by force or by high temperatures. Please take care to use the acetates without crinkling or heating them!** Using the clay, string, tape, white paper, and box, create a shadow box. Create a distinct shape (circle, triangle, rectangle, etc.) approximately 2 cm in size and attach it to one end of the string. Place the box on its longest side with the open side perpendicular to the tabletop. Tape a white screen in place inside the box on the vertical surface opposite the opening. Attach the free end of the string to the top of the box such that the clay shape is suspended in the center of the opening. Connect two light sources such that they light. Arrange the apparatus so the light the shines through the opening of the shadow box past the clay shape and onto the screen. Notice that light is spread more-or-less uniformly over the screen except where shadows are confined to one or more well-defined region(s) on the screen. Separate the two light sources and insert a differently colored acetate close to the bulb between each source and the clay object. Take care when placing the acetates near the bulbs - they may get too hot and begin to melt.		
Initiating Event	Shape the clay into a sphere and suspend by the string. Illuminate the clay with two bulbs, one covered by a red acetate and the other by a green acetate. Observe the shadows on the screen. Invite discussion and observations.		
Required Submissions	Students work in pairs, collaborating on an individual experiment for each student. At least twenty observations from each student pair are required. An original, completed HBL worksheet is required from each student.		
That's odd...	Shadows from two differently colored sources can *still* be made to be black. Aren't those shadows on the 'wrong sides'? The shadow cast by an object illuminated with a single blue light is...yellow. This is possibly the single most intriguing observation Chuck has ever seen! ***COOL!***		
Food for	How **did** those shadows get colored, anyway?		

Figure C.29. HBL Laboratory LC 9 - page 1

Physics 1313
Experiment LC 10 Outline

LC 10 - Illuminating Pigment			
Background	Recall that both light and pigment have primary colors, but that they may be different from one another. Color is typically discussed in terms of what light actually reaches the eye, as it is that light that actually stimulates the cones in the eye and causes the perception of color. Thus, light and pigment are usually broken into two distinct categories, based upon how they actually cause color to be generated. Note that the order below is not meant to imply that either light or pigment uses a particular scheme to generate color.... **Additive** coloration occurs because a particular hue is added to the light leaving the object. Typically this implies that the amount of light leaving the object is *larger* than the amount of incoming light. **Subtractive** coloration is a result of the selective removal of certain colors from the light incident upon the object. This implies that the amount of light leaving the object is *less* than the amount of incoming light.		
Equipment **Group Activity**	overhead projector	colored transparency acetates: magenta, cyan, yellow, red, blue, green	heavy cardstock
	previously prepared sheet from instructor	tape	
Equipment **Individual Activity**	110V bulb holder with incandescent bulb	colored transparency acetates: magenta, cyan, yellow, red, blue, green	multiple colored construction paper sheets, including black and white
	medium-sized, open-topped cardboard box	tape	painted samples from LC 5
Experimental Setup	**This experiment consists of a group activity performed with the instructor and an individual activity.** **Both experimental activities must be performed in a darkened room!** **Note: The acetates can be permanently deformed by force or by high temperatures. Please take care to use the acetates without crinkling or heating them!** **Group Activity** Place the overhead in a darkened room, preferably such that it projects its beam along the long axis of the room. Using the cardstock, create a shield around one colored acetate that keeps any white light from entering the beam. This shield needs to allow changing the acetate used. **Individual Activity**		

Figure C.30. HBL Laboratory LC 10 - page 1

	On the tabletop, lay the cardboard box on its longest side with the open face towards the bulb. Place one colored acetate near the lit bulb so that it keeps any white light from entering the box. Take care when placing the acetates near the bulbs - they may get too hot and begin to melt. Place construction paper or a painted sample inside the box and illuminate it with the colored light. The function of the box in this experiment is to provide an environment where the experimenter can control the ambient light color.
Initiating Event	**Under no circumstances should the previously prepared sheet be illuminated in *white* light!** **Group Activity** Project a colored beam from the overhead with one of the acetates (specify) onto the previously prepared sheet. Invite discussion and observations. Repeat this activity using two additional acetates (specify). Invite discussion and observations. Wonder aloud: "What are these colors?"
Required Submissions	Students work in pairs, collaborating on an individual experiment for each student. At least twenty observations from each student pair are required. An original, completed HBL worksheet is required from each student.
That's odd...	Blue pigment under green light appears to be *black*. Magenta pigment under magenta light appears normal, but under blue light appears *blue*.
Food for Thought	Why **did** the colors change? Shouldn't the perceived color of the illuminated pigments result from the 'mixture' of the light colors? Is paint colored due to additive or subtractive mixing? What about light?

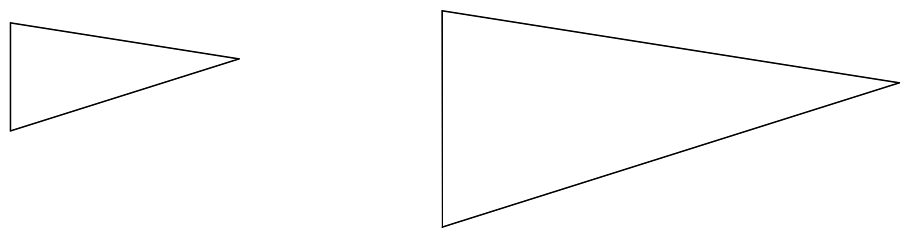
Figure C.31. HBL Laboratory LC 10 - page 2

C.4.2 HBL Class Activities

The 2 Light and Color HBL class activities appear in this section.

Physics 1313
LC Lecture 1 Notes

Similar triangle information:
In the figure below, two triangles that are similar to one another are shown.



Note that similar triangles have certain features that are the ***same*** for both triangles, and other aspects which are ***proportional*** to one another. Similar triangles have all corresponding interior angles the same and the lengths of all sides in the same proportion. Thus, if one side of a triangle has a length of 5 units and the corresponding side of the similar triangle has a length of 15 units, then all of the sides of the similar triangle will be related in length to the sides of the original triangle in the same proportion (here, the proportion is 15/5 = 3).

In class, we will develop a relationship between the lengths of the sides of a special kind of triangle.

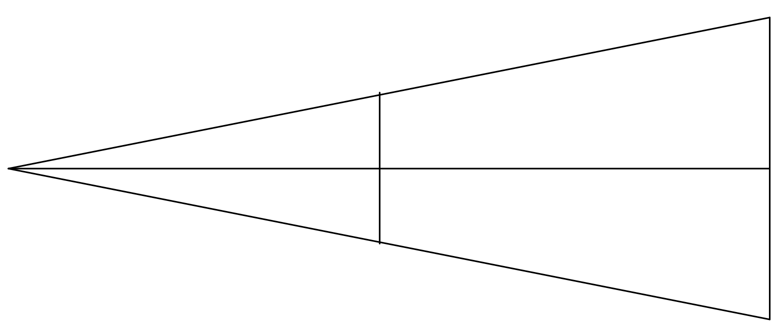


Figure C.32. HBL LC Lecture 1

HBL LC Lecture 1

LC 1 – Reflecting Color

The 'stuff' light encounters as it travels is commonly referred to as the **medium**. Light may interact with a medium in one of four fundamental ways: it may propagate, be reflected, refracted, or absorbed. **Propagation** indicates that light simply travels through a transparent medium. Light that makes it through the medium is said to be **transmitted**. **Reflection** occurs when the light encounters the surface of a material different from the one it is traveling through. The light changes direction as a result of the interaction with the new surface, but does not actually *enter* the reflective medium. **Refraction** is the change in direction of light's travel (bending) as it goes from one medium into another. **Absorption** is the loss of light as it travels through the medium.

- ✓ Light travels along a straight path and only changes direction when it interacts with a medium or a surface.
- ✓ An interaction between the paper and the light determines the reflected color.

LC 2 – Masked Lights 1

Light may be deviated (bent) by a small amount as it passes the surface of an object or goes through an opening in a solid object - this is called **diffraction**. Diffraction effects are usually quite small, and should not be confused with the 'blurring' caused by light rays from an extended source.

LC 3 – Masked Lights 2

Superposition is when two or more images are displayed one on top of the other or when several things are being done at the same time and their effects add.

- ✓ The image caused by a light source is caused by light moving along straight lines – this inverts up and down, left and right, but does not alter the shape of the cutout in the mask.
- ✓ Extended sources cause images using superposition.
- ✓ Similar triangles can be used to explain size issues.

LC4 – Shadows 1

When light encounters an **opaque** medium (one that does not transmit light) it is usually absorbed or simply blocked. Only light rays not encountering the opaque medium will continue past the obstruction. **Shadows** are caused by a reduction in the amount of light striking a screen or other reflective surface. The difference in the amount of light on the reflective surface is perceived as the place receiving less light being 'darker' in comparison to the well-lit region.

- ✓ Shadows are shaped and sized by the same mechanisms as images.

LC5 – Mixing Pigments

Hue is the general color we are referring to, such as red, green, or orange. Think of hue as the color being discussed. **Value** refers to the relative lightness or darkness of a particular hue. For instance, "sky blue" and "navy blue" are both blue in hue, but one is light and the other is dark in value. **Saturation** refers to the brightness of a particular color as compared to the brightness of the same color when generated by a prism. Value and saturation are easily confused, but remember that saturation represents purity of a color, while value indicates lightness or darkness of that hue.

Colors can also be separated into groups according to the following grouping definitions:
Primary colors of pigment are those that cannot be made using a combination of other colors. A complete set of primary colors allows creation of all other colors. Combinations of primary pigments result in **secondary colors**. **Complementary colors** are pairs of colors: pick a primary color and then identify the secondary color having none of the chosen primary.

Figure C.33. HBL LC Lecture Wrap Up Activity - page 1

Human vision uses different structures (named for their shape) to detect light. **Cones** detect color information and are sensitive to one of three colors of light: reddish, bluish, or greenish. **Rods** confer information regarding black and white. All other colors are 'seen' by stimulating those receptors in combination with one another while the brain interprets this simultaneous stimulation as a distinct color.

Colorblindness indicates a person either has a reduced ability to perceive a particular color or that they cannot see the color at all. Colorblindness is named for the colors the person has difficulty distinguishing and comes in several varieties, including red-green (most common) and yellow-blue (very rare). Colorblindness affects only a small fraction of the population (5% - 8%) and is much more likely in men than women. It is thought that colorblindness has a few causes: differences in pigments used to detect light in the cones, absence of those pigments in cones, nerve damage causing incorrect stimuli to be sent to the brain, or problems in the brain itself causing misinterpretation of color information.

- ✓ Pigment obtains its color by reflecting only the colors of light that mix and cause that color.
- ✓ Pigment absorbs the other primaries used to illuminate it.
- ✓ Pigment mixes when the colors are physically mixed.
- ✓ The primary colors of pigment are magenta, cyan, and yellow.
- ✓ The secondary colors are red, blue, and green.
- ✓ Magenta is complementary to green, cyan to red, and yellow to blue.
- ✓ The presence of all pigment primaries yields black.

LC6 – Markers and Chromatography

Solids that disappear 'into' a liquid are said to be **soluble** in the liquid, and the degree or extent to which they become incorporated into the liquid is termed **solubility**. The liquid capable of dissolving a solid is termed a **solvent**. Not all solids are soluble in a given liquid, nor are all liquids capable of dissolving a particular solid. Other liquids and even gases may be soluble in a given fluid. Fluids that are soluble in one another may be mixed, and are termed **miscible**, while fluids that are not are called **immiscible**. The movement of one substance within another is called **diffusion** and always causes high concentrations of one substance to be redistributed to more uniform lower concentrations throughout another substance.

Cohesion, or affinity of a fluid for itself, accounts for how a fluid forms into drops or how it is shaped when it touches the sides of a container. Any part of a fluid that is on the surface feels 'pulled' into the bulk of the fluid by this cohesion, and results in the surface of the water acting like a sheet that has been pulled taught or the surface of a trampoline. The measure of this 'pull' on the surface of a fluid is called **surface tension**. The affinity of a fluid for other materials is called **adhesion**. The 'thickness' of a liquid is called **viscosity**. Many different aspects of fluids may interact simultaneously to provide interesting effects. **Capillary Action** is a good illustration of this: a fluid may utilize both cohesion and adhesion to allow it to 'climb' through small cracks or over surfaces, while viscosity serves as a limiting factor to this behavior.

Paper Chromatography is the process of using a liquid solvent to 'spread out' the components of a mixture onto a paper medium.

- ✓ Pigment in markers works the same way as in paint.

LC7 – Mixing Light

- ✓ Light mixes when two distinct beams overlap or are simultaneously detected by the eye.
- ✓ The primary colors of light are red, blue, and green.
- ✓ The secondary colors are magenta, cyan, and yellow.
- ✓ Magenta is complementary to green, cyan to red, and yellow to blue.
- ✓ The presence of all light primaries yields white.

Figure C.34. HBL LC Lecture Wrap Up Activity - page 2

LC8 – Prisms and Acetates
Which way light bends, and how much it bends is determined by the material the light is initially in and by which material it will enter. This phenomenon may give rise to interesting effects, including the ability of a prism to display a full 'rainbow' of color - a **spectrum**. Every transparent material bends light by a different amount, and this is characterized by a property called **index of refraction**. The index of refraction of a material (or index) is a number that indicates how the light gets slowed down as it propagates through the material. High index materials allow light to move more slowly through them than low index materials.

If two differing materials are placed in contact with one another, we call the place where their surfaces touch the **interface**. We can also define a unique direction with regard to the interface. It is customary to define the direction perpendicular to the plane of the interface as the **normal** direction. Normal, in this mathematical context, simply means perpendicular.

If light is traveling through a low index material and then encounters a different material with a higher index of refraction, it will slow down. Because of the change in the speed of the light's travel, the light in the new material is shifted to an angle closer (towards) the normal. If light is traveling through a high index material and then encounters a different material with a lower index of refraction, it will speed up as it enters the new material. This increase in speed causes the light to bend away from the normal on the other side of the interface.

Each different color may be bent by a different amount by the same material, even if it is allowed to enter the material in a uniform manner. This separation of colors by a material is called **dispersion**.

- ✓ Prisms disperse light – red the least, blue the most.
- ✓ Acetates work by only allowing the primaries used to create that color to pass.
- ✓ Acetates absorb the other primaries from the illuminating light.
- ✓ Magenta and cyan do not appear in the spectrum, but do appear when two spectra are overlapped. Thus, they are **physiological** in nature.

LC9 – Shadows 2

- ✓ Shadows formed in the presence of colored light work as before, except have the added feature of blocking some of the light from another source, coloring the shadows.
- ✓ Colored shadows may be formed with only one source, but they are physiological in origin.

LC10 – Pigments under colored light
Color is typically discussed in terms of what light actually reaches the eye, as it is that light that actually stimulates the cones in the eye and causes the perception of color. Thus, light and pigment are usually broken into two distinct categories, based upon how they actually cause color to be generated. **Additive coloration** occurs because a particular hue is added to the light leaving the object. Typically this implies that the amount of light leaving the object is larger than the amount of incoming light. **Subtractive coloration** is a result of the selective removal of certain colors from the light incident upon the object. This implies that the amount of light leaving the object is less than the amount of incoming light.

- ✓ Concentrate on the LIGHT to determine the color seen.
- ✓ Overlapped light beams add colors
- ✓ Overlapped pigments subtract colors
- ✓ Light beams on pigment have some colors removed
- ✓ Light shone through many acetates.

Figure C.35. HBL LC Lecture Wrap Up Activity - page 3

C.5 Astronomy by Sight

All Astronomy by Sight HBL material created for Physics 1313 is presented in this section.

C.5.1 HBL Laboratories

All 3 HBL Astronomy by Sight Laboratories appear in the following Figures.

Physics 1313
Experiment AbS 1 Outline

<table>
<tr><th colspan="4">AbS 1 - Sun Plots 1</th></tr>
<tr><td>Background</td><td colspan="3">Over the course of the semester, we will create several sets of data that show information about the sun over the course of a single day. This data is called a sun-plot (SP), and is taken using the equipment provided. Should you need to create your own sun-plot apparatus, use a relatively thin flat board at least 12" square. Drive an 8d (read this as "eight penny") or larger nail perpendicularly through the geometric center of the board. This nail will be used to cast a shadow onto paper placed on the board, and is called the gnomon. Gnomon is pronounced "no-mun". The gnomon should protrude at least 4 cm through the board.

Sun-plot data is taken on a sheet of paper placed on the board with the nail piercing the paper near its center. We recommend that the paper be taped on the board securely so it does not blow away or change its orientation relative to the board. As the day progresses, data is taken by pressing the paper firmly onto the board and marking the tip of the shadow cast by the gnomon on the paper. After marking the shadow position, indicate the time that data was taken. A complete sun-plot consists of many individual data points over the course of the day. Please see the Homework page for additional details regarding sun-plots.

Reminders about sun-plots:
The following information should be displayed on every sun-plot:
• Your name
• The current sun-plot number (for grading purposes)
• The date
• The height of the gnomon above the surface of the board in millimeters
• A compass rose indicating the orientation of the board relative to the compass directions
• Landmarks to reposition your board should it get moved
• The gnomon position must be circled
• At least ten data points no closer together than 30 minutes
• The time of each data point

A completed sun-plot should have a minimum of ten points covering at a time span of at least five hours. Data should be taken every half-hour to hour, but gaps of up to 1.5 hours are acceptable. You may recruit help in taking sun-plots from friends, room-mates, significant others, family members, or classmates. Regardless of who helps whom with sun-plot data, all sun-plots must be:
• original - they must have been taken on their own sun-plot board
• signed by the person who helped with data collection
• clearly dissimilar to anyone else's data

Please adhere to the above guidelines, as academic dishonesty has been a problem in the past with sun-plots.</td></tr>
<tr><td>Equipment</td><td>sun-plot board and paper</td><td>current sun-plots (optional)</td><td>flashlight</td></tr>
</table>

Figure C.36. HBL Laboratory ABS 1 - page 1

Experimental Setup	**This experimental set-up must be prepared prior to the lab.** Place the sun-plot board in an appropriate location outdoors and record all pertinent information on the paper. Record two data points about 15 minutes apart immediately before the class starts. No additional equipment is available for this lab.
Initiating Event	While the board is in the data-taking position outdoors, invite students to observe the sun-plot apparatus carefully. Invite discussion and observations. Record an additional data point after observing for approximately 15 minutes. Invite discussion and observations. Return to the classroom and distribute the flashlights. Mention that the room may be darkened if desired.
Required Submissions	Students work in pairs, collaborating on an experiment for **each** student. At least twenty observations from each student are required. An original, completed HBL worksheet is required from each student.
That's odd...	Altering the gnomon may cause changes in the data. The sun comes up in the east, right? The data does not seem evenly spaced. The center of the sun-plot data is not at noon.
Food for Thought	It seems that the shadows cast by the gnomon display a repetitive curvature. Why is the morning data to the *west* of the gnomon? Doesn't the sun get directly overhead at noon?

Figure C.37. HBL Laboratory ABS 1 - page 2

Physics 1313
Experiment AbS 2 Outline

AbS 2 - Sun Plots 2			
Background	As the semester has progressed, we have noted that the sun-plots have altered their shapes in a continuous manner. One of the more interesting questions that arises from these alterations is regarding the nature and causes of the changes. Are the differences in the sun-plots caused by differences in data-taking technique, or are they real? If so, what causes them? Recall from the data technique training at the beginning of the semester that we defined the **Altitude** of an object in the sky to be the angle the object is above horizontal, with the understanding that we measure from directly (vertically) below the object to minimize the angle. Altitude information may be obtained from the sun-plot by understanding how the data was taken. The maximum altitude an object can have is 90º, which is directly overhead. An object's maximum altitude position is called its **zenith**, while its lowest (minimum altitude) position is referred to as its **nadir**. Altitude information refers to the object relative to the horizontal. If we wanted to specify where the object was relative to the compass directions, we would need another term. Therefore, we define the **Azimuth** of an object in the sky to be the angle between North and a line extended to the horizon vertically below the object. Azimuths are, by convention, always measured in a *clockwise* direction. In degrees, North has an azimuth of 0º (or 360º), East is 90º, South is 180º, and West is 270º. Two other calendrical terms that refer to specific days may become useful during the semester. While the length of a single day, say from sunrise to sunrise, is understood to take 24 hours, the length of the daylight and night-time hours varies with the seasons and calendar date. The days having equal hours of daylight and night are called **Equinoxes**. The **vernal equinox** is in the spring near 20 March of every year, while the **autumnal equinox** is in the fall around 23 September. **Solstices** are days which have the most or least number of daylight hours of any days during the year. The **summer solstice** or longest "day" of the year is near 21 June, while the shortest "day" of the year or **winter solstice** is 21 December. Traditionally, equinoxes and solstices are taken as the beginning days of the seasons.		
Equipment	3 or more current sun-plots, spanning at least three weeks	sun-plot board	flashlight
	ruler	protractor	
Experimental Setup	Place one of the sun-plots on a sun-plot board. No additional equipment is available for this lab.		
Initiating Event	Invite students to observe the sun-plots carefully. Invite discussion and observations. Wonder aloud if the sun-plot gives information regarding the motion of the sun. Invite discussion and observations.		

Figure C.38. HBL Laboratory ABS 2 - page 1

	Mention that the room may be darkened if desired.
Required Submissions	Students work in pairs, collaborating on an experiment for **each** student. At least twenty observations from each student are required. An original, completed HBL worksheet is required from each student.
That's odd...	Sun-plots from differing weeks are not identical, even if the equipment used was identical. The sun comes up in the east, right? The data may impart both altitude and azimuth information.
Food for Thought	It seems that the shadows cast by the gnomon display a repetitive but dissimilar curvature. Is the sun moving relative to the horizon at sunrise or sunset? What is the sun's zenith?

Figure C.39. HBL Laboratory ABS 2 - page 2

Physics 1313
Experiment AbS 3 Outline

<table>
<tr><th colspan="4">AbS 3 - Synthesis of Moon Information</th></tr>
<tr><td>Background</td><td colspan="3">The results of the mood data analysis revealed underlying patterns in the behavior of the moon over some period of time. We define a lunar month to be the amount of time necessary for the moon to begin at one particular phase (the new moon) and then return to that phase. One of the patterns extracted from the data is that the phases follow a particular order in their progression throughout the lunar month. Another pattern that emerged was that some of the phases are seen only at certain times: for instance, the full moon is usually seen in the early evening through early morning and never during the majority of daylight hours. Our ultimate goal in this module is to develop a model that explains the patterns the moon displays and that allows successful prediction of certain types of behavior.

Eclipses occur when an object that should be visible cannot be seen. There are two types of eclipses for the earth-moon-sun system: eclipses of the sun and eclipses of the moon. A lunar eclipse is when the moon cannot be seen, while a solar eclipse is when the sun cannot be seen. Eclipses are interesting and potentially terrifying events. They do not occur often: on average, each type of eclipse occurs about twice per year. Unfortunately, not every eclipse that occurs is visible from any specific location on earth. One final interesting thing about eclipses is that they seem to happen in "seasons" - that is, they usually happen only in certain well-defined times, approximately every 173 days.

For convenience, we will define a average day (or perfect day) to be a day when the sun rises at 6:00 am, has noon at 12:00 pm, has sunset at 6:00 pm, and midnight at 12:00 am. Although this may seem strange (and not very realistic), it will help us when we are attempting model development.</td></tr>
<tr><td>Equipment</td><td>overhead projector</td><td>small styrofoam balls, 3" - 6" diameter</td><td>moon data from previous exercise</td></tr>
<tr><td>Experimental Setup</td><td colspan="3">These experiments must be performed in a darkened room.

Arrange the overhead projector such that projects its beam of light into a relatively long darkened room. Each student group will receive two styrofoam balls. No additional equipment is available for this lab.</td></tr>
<tr><td>Initiating Event</td><td colspan="3">If students have not already done so, have them re-examine their data, looking for correlations between the major phases of the moon and the sun-moon angle. Have them place their results in a data table.

Have each student group display a particular table of relevant information generated in the moon data analysis activity: moon phase progression for an entire lunar month, the sun-moon angle for each phase, and the rise and set times for each phase.

Solicit observations regarding each set of data. Solicit explanations of the moon's behavior that are</td></tr>
</table>

Figure C.40. HBL Laboratory ABS 3 - page 1

	consistent with the data tables. Remind the students that explanations are *testable*, and indicate the available equipment. After half of the class time has elapsed, draw the following diagram on the board: a first quarter moon is at its highest point directly above the southern horizon. Pose the question: "What time is this?"
Required Submissions	Students work in pairs, collaborating on an experiment for each student. At least twenty observations from each student are required. An original, completed HBL worksheet is required from each student. Additionally, a copy of all the pertinent moon data in table form is required.
That's odd...	The earth's shadow can cause phases. Sometimes observers on the earth cannot see the moon, but the sun is visible at that time. Eclipses do not occur every month. Where is the moon when it is in the new moon phase?
Food for Thought	How can the progression of phases be explained with a physical model? Why should eclipses be spaced so far apart, but be relatively evenly spaced? Which is larger - the moon or the sun? What is the evidence supporting this claim? Most anyone can estimate the time by looking at the sun in the sky. Can this feat be done with the ***moon***?

Figure C.41. HBL Laboratory ABS 3 - page 2

C.5.2 HBL Class Activities

All 3 HBL Astronomy by Sight class activities appear in the following Figures.

HBL AbS Cosmological Activity

This semester, you have taken several sun-plots. These pieces of data reveal clues to what may be happening to the Earth – Sun system throughout the semester.

Can you create at least two different models that will explain why we get “day” and “night” on Earth? Detail all specifics for each of your two models.

We define **local noon** as the time of the shortest shadow on a given day’s sun-plot.

Follow-up Questions:

These questions should be submitted in typed form at the beginning of the next class.

Detail each of the models you created to give rise to “day” and “night” on Earth. You may find pictures helpful ways to represent some aspects of your model. Be as specific as you can – give timing information, relative angles, etc.

How and when does local noon occur? Is there any physical significance to the concept?

Does local noon change in any way? How does this happen?

Do your models explain why the number of daylight hours changes during the year? Since we know this actually happens, your models must explain why this is so. Give specific reasons for the changes.

When are the following four “special” days and what happens on each day: vernal equinox, summer solstices, autumnal equinox, and winter solstice.

How does the Earth get “seasons”? Be specific and include whatever evidence we have for your model!

Does the sun rise and set above the exact same positions over the horizon from day to day? Explain how you know how to answer this question.

Is the altitude of the sun the same at every local noon? What can you conclude from this?

The features of the sun-plots changed over the course of the semester. Predict how they will change for the rest of the year, and give an explanation for the changes you observed.

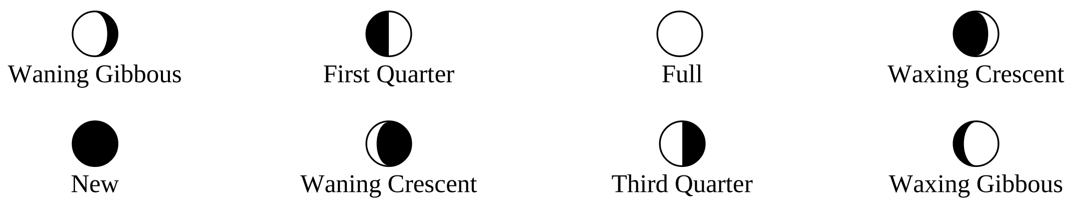
Can you choose between your models based upon the evidence you have?

Figure C.42. HBL AbS Cosmological Activity

HBL AbS Moon Data Analysis

You have learned how to take moon observations this semester, and the results of approximately 11 weeks of observations from all course members are summarized in an additional handout or class display. What we now desire is a model allowing some understanding of how the moon attains the phases it has, if the phases occur in some pattern, and if there is any regularity to the phases. We begin our analysis by making careful observations and deductions from the data, allowing the data to guide any models created and provide tests of model predictions.

The major phases of the moon are listed below, in no particular order. The dark portion of the diagram represents the portion that is not well lit.



Analyze the data given in the class handout, providing support for your answers to the following questions. Typewritten responses to all questions will be collected at the beginning of the next class period.

The goal of this exercise is to organize the observations so they may form the basis of a model explaining the behavior of the moon, and to answer some potentially problematic questions before model development.

Follow-up Questions:

Chuck has noticed that data taken at the same place and at the same time by different observers can be quite different. What is your explanation for this? Does this observation reveal any types of error associated with the data? How will you decide which observations to “believe”? How will you deal with the disparity in the observations?

Do the phases of the moon occur in any repeatable pattern? What are the major features of this pattern, or is the order of the phases completely random?

Are there any other phases (aside from those above) seen in the data? What does this tell you?

Are there any phases not directly observed in the data? What does this tell you?

Are there any additional relationships between some of the recorded data and the phase?

Can you infer when each major phase of the moon rises and sets? What about when the moon is at its zenith? Are there any patterns here? Clearly explain how you came to your conclusions. Create a table showing your answers.

Figure C.43. HBL AbS Moon Data Observations and Analysis Activity

HBL AbS Lecture 1

We have been much concerned with models explaining how our sun, the moon and the earth interact to give rise to day and night, as well as models allowing explanation of the phases of the moon.

Sun-plots

Sun-plots have taught us many things this semester: they give us a way of knowing what the sun does over the course of the day and how that changes with time. A sun-plot will allow us to find **local noon**, the time of the shortest shadow. Notice that the sun-plots are all symmetric about the shadow of the gnomon at local noon, with the shortest shadow pointing due northwards and corresponding to the highest position of the sun in the sky. We call the largest altitude of any object in the sky the **zenith**, while the lowest point is called the **nadir**.

Models explaining the data generated in a sun-plot must be capable of reproducing the major features of the data. For instance, it was noted that the arc of a sun-plot became a straight line near the equinox. An **equinox** occur when the daylight and nighttime hours are equal, generally around 20 March and 23 September. Unfortunately, no class data from this semester is available for either **solstice** – the time when the daylight hours are either a maximum or a minimum, usually around 21 June and 21 December.

Follow-up Questions: Sun-Plots

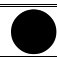
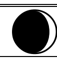
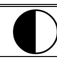
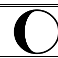
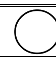
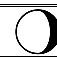
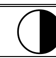
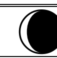
Using an overhead projector, a styrofoam ball, and a toothpick (or other small straight object), can you demonstrate what has to happen for the sun-plots to have the shape they do?

How can the model used to explain sun-plots be tested?

Which model explaining day and night is “correct”? What data allows this deduction?

Moon Data

We have investigated the phases of the moon for most of the semester. Upon analyzing the data, we discovered that the moon completes one cycle of phases in approximately 30 days. We refer to the amount of time a repetitive cycle takes as the **period** of that cycle. A table summarizing some of the pertinent information extracted from analysis of the moon data is presented below. Note that for the purposes of the table, we are utilizing the assumption that every day is exactly the same, with 12 hours of daylight and having sunrise and sunset equally spaced. The dark portion of the diagram represents the portion that is not well lit.

Day (approximate)	0	3.75	7.5	11.25	15	18.75	22.5	26.25
Phase								
Phase Name	New	Waxing Crescent	First Quarter	Waxing Gibbous	Full	Waning Gibbous	Third Quarter	Waning Crescent
Rise Time	6:00 am	9:00 am	12:00 pm	3:00 pm	6:00 pm	9:00 pm	12:00 am	3:00 am
Zenith Time	12:00 pm	3:00 pm	6:00 pm	9:00 pm	12:00 am	3:00 am	6:00 am	9:00 am
Set Time	6:00 pm	9:00 pm	12:00 am	3:00 am	6:00 am	9:00 am	12:00 pm	3:00 pm
S-M Angle	0º	45º	90º	135º	180º	225º	270º	315º

Utilizing the information extracted from the data, it was discovered that there is an underlying relationship between the phase of the moon, the position of the moon relative to the horizon and cardinal directions and the time. In fact, if any two of the above items are specified, the third may be deduced from the model.

Follow-up Questions: Moon Data

There are several ways two of the three variables listed above may be used to determine the third. Detail how this can be done for each of the variables.

Does the shadow of the earth cause the phases of the moon? Explain how you know.

What causes eclipses? Be specific! Does your answer support the idea that the sun and moon are not equidistant from the earth?

Figure C.44. HBL AbS Lecture 1

C.6 Heat and Temperature

All Heat and Temperature HBL material created for Physics 1313 is presented in this section.

C.6.1 HBL Laboratories

All 10 HBL Heat and Temperature Laboratories appear in the following Figures.

Physics 1313
HT 1 Experiment Outline

HT 1 - Measurement of Physical Quantities	
Background	Studying nature involves collecting **data** (information). A single piece of data is generally referred to as a **datum** or a **value**, while the total set of information is generically called **data**. There are two major types of data that may be obtained. **Quantitative** data is numerical information: how many of something there are, how large the ship is, the cost of an item, how long a person waits in line before leaving, etc. **Qualitative** data is non-numerical information: are the subjects agitated, is the reaction to a change liked or disliked, satisfaction of a customer with a product, etc. Some data is difficult to place in either category, and it is only by carefully defining the term (and the manner in which it is to be measured) that the type of data to be collected becomes apparent. Most of the data collected in this module will be quantitative, meaning we should develop techniques for presenting the data in a meaningful way. **Data tables** are convenient summaries of data. These usually place data in columns under headings indicating what every entry in the column represents and the units used in its measure. It is considered good form to have a title for data tables that summarize the information presented, such as "Height of corn plant at various times", or "Height versus time data for the growth of a corn plant". **Graphs** are specialized pictorial representations of data and are particularly effective in indicating trends or relationships between quantities. Graphs represent data as a series of points on a plane defined by a set of coordinate axes. Just as with data tables, graphs usually indicate the units used for all quantities and have titles indicative of the data being studied. Many different aspects of a system may be numerically measured. The **mass** of an object is a number related to its 'heaviness' when on the surface of earth. It is quite difficult to alter the behavior of a massive object, while objects having small masses are easily disturbed. Mass is usually measured with springs, scales, or balances. For the purposes of this course, mass will be measured in grams (g) or kilograms (kg). The physical size of an object may need to be measured. Because the actual meaning of 'size' is only clear by examining the context of its use, we subdivide the idea of size into three (or more) more specialized meanings that depend upon the number of spatial dimensions used in the measure. Notice that all size measurement methods may have difficulty with irregularly shaped objects like a partially smashed piece of clay or a crumpled sheet of paper. **Length** of an object generally refers to the longest measure that may be obtained when using a ruler to measure the object along a straight line. The usual units used to indicate length are centimeters (cm) or meters (m). Another indication of the size of an object may refer to how much two-dimensional 'stuff' is needed to measure it. We refer to this measure as **area** and subdivide the concept into two types. **Surface area** indicates how much two-dimensional stuff is needed to completely cover the object. This is clear in the case of wrapping a gift - a certain amount of paper is needed to cover its surface. **Cross-sectional area** indicates how much two-dimensional stuff is covered when the object is placed upon a flat surface. This is analogous to placing a box onto tissue paper - the

Figure C.45. HBL Laboratory HT 1 - page 1

	amount of paper covered would indicate the cross-sectional area of the box. Area, of either type, is usually measured in square centimeters (cm^2) or square meters (m^2). An object's **volume** indicates the amount of three-dimensional 'space' it occupies: an uninflated balloon has much less volume than when inflated. Sometimes the volume of an object may be calculated after performing certain measurements, much like calculating the distance around a circle after measuring its diameter. Under certain circumstances, objects may be immersed in a fluid and their volume deduced from the displaced liquid. It is customary when reading the measuring instrument to measure to the bottom of the curved fluid surface. Volume usually has units like cubic centimeters (cm^3), cubic meters (m^3), liters (l), or mililiters (ml). **Temperature** is an indication of the relative 'hotness' or 'coldness' of an object or environment and is measured with a thermometer. Thermometers may come in many varieties, including digital, spring, and glass. Temperature may even be measured electrically. There are several unit systems used in measuring temperature, but we will use degrees Celcius (°C) or degrees Fahrenheit (°F). Two aspects of data collection should be brought out: data may be accurate and precise. **Accuracy** refers to the ability of the measuring device to produce data that is close to the 'real' or 'true' value. The **precision** of an instrument indicates the number of digits in the value that have meaning. Good instruments should be both accurate and precise. Any measurement will contain some error that cannot be eliminated by using better measuring technique. This **uncertainty** is a property of the instrument used and is present in all measurements made with that instrument. As a general guideline, an instrument's uncertainty is smaller than the smallest measurement that can be made using the device. Clearly this must be the case, since values outside this range are readily distinguishable. Note that uncertainty is a function of the instrument used and does not include 'human error', as it assumes use with 'perfect' technique. The uncertainty of an instrument is mathematically defined as the largest difference between any data value and the average of the set of data. **Calibration** of an instrument may refer to one of two things. An instrument needs gradations, markings, or some way of being read - the process of obtaining these readings is called calibration. Thus, marks of a repeatable size are indicated on a ruler, the amount of stretch in a spring is recorded when known weights are placed upon it, or a beaker is marked when filled with a known amount of fluid. Another meaning for calibration is the adjustment of the instrument to insure it measures accurately. For instance, when stepping on the bathroom scales one may notice that they do not always read 'zero' *before* they are stepped upon. They are adjusted to read 'zero', insuring that they return data that reflects reality - obviously they cannot *really* measure nonzero weights with nothing upon the scales!. Another instance showing the need for calibration involves automobiles: as they travel, small amounts of rubber are removed from the tires causing the size of the tire to change (and ultimately leading to their replacement). This loss of circumference will cause a difference between the speedometer reading and the actual speed over the ground as the tire wears. Thus, the speedometer may report a speed of 65 kph when the *actual* speed could be 61 kph or 68 kph.		
Equipment	electronic scales	graduated cylinders: 10 ml, 50 ml, 100 ml, 250 ml	pyrex beakers: 50 ml, 100 ml, 250 ml, 500 ml
	Celcius and Fahrenheit	water	solid waterproof objects:

Figure C.46. HBL Laboratory HT 1 - page 2

	thermometers		metal, wood, plastic, clay, wax, etc.
Experimental Setup	**This experiment consists of two group activities performed with the instructor and an individual activity.** **Group Activity 1** One of the following situations should be given to each group: • 1) Place some water in a container and supply a thermometer. • 2) Place some water in a graduated cylinder. • 3) Place some water in a beaker. • 4) Supply a solid object and a ruler. **Individual Activity** Each group should have the above items readily available.		
Initiating Event	**Group Activity 1** Each individual within a group will measure the indicated property. **Measurements will be made without consultation of other group members, and will be recorded without sharing the results with anyone else.** The measurements should be recorded anonymously and collected. After all measurements have been made, post the results. Invite discussion and observations. **Group Activity 2** **This experiment will run "in the background" while individual activities are performed.** Set up situations similar to the above activities using the 10 ml and 100 ml graduated cylinders, one beaker, centimeter ruler, and Celsius thermometer. Each individual will measure the indicated property from every station's equipment. **Measurements will be made without consultation of other class members, and will be recorded without sharing the results with anyone else.** The measurements should be recorded anonymously and collected. After all measurements have been made, post the results. Invite discussion and observations. Calculate the uncertainty of each instrument.		
Required Submissions	Students work in pairs, collaborating on an individual experiment for each student. At least twenty observations and two data tables from each student pair are required. An original, completed HBL worksheet is required from each student.		
That's odd...	Several individuals measuring the same quantity usually get *different* numerical answers. Water surfaces in a container do not always 'curve' the same way.		
Food for Thought	Is it possible to *operationally* define mass, volume, and temperature? Can an object have several properties simultaneously?		

Figure C.47. HBL Laboratory HT 1 - page 3

Physics 1313
HT 2 Experiment Outline

HT 2 - Temperature and Calorimetry			
Background	The **Celsius** temperature scale is based upon the physical properties of pure water under certain circumstances at the earth's surface. Under those circumstances, pure water freezes at 0 °C and boils at 100 °C. Other temperature scales, such as the Fahrenheit scale, may be related to the Celsius scale in a mathematical way. **For the purposes of this course, we will measure temperature in degrees Celsius. We will *always* estimate all temperatures to the nearest tenth of one degree (0.1 °C).** In the interests of clarity, we will refer to the reading obtained with a correctly-used thermometer as the **temperature** of an object. This is distinctly different from the amount the object's **temperature change**, which reflects the fact that the temperature began at a particular value and ended at another value. This is mathematically defined to be the final temperature minus the initial temperature. Changes in temperature may be caused by many things, and careful attention needs to be paid to the interaction of the system under study and the environment containing the system. Most of the time, we are interested in minimizing this interaction and take precautions to carefully control it. When the system is does not interact with its environment much or at all, it is said to be **isolated**. When two or more objects are placed in contact, they may experience a change in their temperatures. Because the objects are all affected, we call this situation a **thermal interaction** or simply an **interaction** (where it is understood we are referring to temperatures). Many times, we will be interested in how two or more objects interact and wish to isolate the system to control the influence of any other experimental variables. This type of study is known as **calorimetry**, and allows many interesting deductions to be made. For instance, it is through calorimetry that we know the calorie content of food, the amount of energy contained in fuels, or the times necessary to cook certain foods.		
Equipment	Celsius and Fahrenheit thermometers	various waterproof containers: styrofoam, wood, glass, metal	stopwatch
	graph paper	hot water (approximately 50 °C - 60 °C)	
Experimental Setup	Each group should have the above items readily available.		
Initiating Event	Carefully measure the hot water's temperature. Place thermometers into two glass containers and add hot water in different amounts to each. Start stopwatches for each container when liquid is first placed into them. Take temperature readings at 15 second intervals. After four minutes, stop collecting data. One student should read the stopwatch for each container, one student should read the		

Figure C.48. HBL Laboratory HT 2 - page 1

	thermometer in each container, one student should act as data recorder for both situations and one student should graph the results of both experiments on the same graph. While this process is ongoing, invite discussion and observations. Invite discussion and observations regarding the graph.
Required Submissions	Students work in pairs, collaborating on an individual experiment for each student. At least twenty observations, one data table, and one graph from each student are required. An original, completed HBL worksheet is required from each student. Graphs and data tables may be attached to completed HBL worksheets. **Note:** Graphs and data tables (and the information contained in them) count as *single* observations!
That's odd...	Containers placed on wooden surfaces behave differently than those placed upon concrete. The act of pouring has a measurable effect on temperature.
Food for Thought	Why can *any* portion of an object usually be measured to obtain the object's temperature? The slope of a graph may provide interesting information under the correct circumstances. Doesn't the addition of the thermometer *alter* the object's temperature?

Figure C.49. HBL Laboratory HT 2 - page 2

Physics 1313
HT 3 Experiment Outline

HT 3 - Variable Conservation			
Background	Variables under study may remain constant or change in value. Those variables that remain constant after an operation or process are said to be **conserved**. Rules that deal with the behavior of the system in terms of conserved variables are referred to as **conservation laws**, and are among the most powerful ideas in science. Conservation laws are rules that indicate variable values that do not change under a very wide variety of situations, explaining why they are called *laws*. Less general rules that tell the behavior of the system under restricted circumstances are called **principles**. Principles indicate how variables change under quite restricted sets of circumstances, and it is important to specify the restrictions on their use. For instance, the volume of a cup made of metal is measured. Every time the volume is measured, it is found to be the same value, at least to within the precision of measurement and the uncertainty of the device used in measuring. This seems to indicate that the volume of the cup is constant, and it could be postulated that the volume of the cup will always have the same value, regardless of situation. However, it is later discovered that the volume measured when using *hot* liquids results in a *different* value. Thus, the volume of the cup is not *really* constant, but rather depends on the temperature of the fluid being measured. It is inappropriate to suggest a "law of volume conservation" for the cup, since we have demonstrated that the volume changes. Rather, we may postulate a "principle of volume conservation" for the cup, but we must specify that the temperature of the system is one particular value when making measurements, otherwise the volume may vary.		
Equipment	Celsius thermometers	various waterproof containers: styrofoam, wood, glass, metal	hotplate
	graph paper	hot water (approximately 50 °C - 60 °C)	cold water (approximately 10 °C)
	electronic scales	graduated cylinders	ice
	sugar	salt	stopwatch
Experimental Setup	Each group should have the above items readily available.		
Initiating Event	Place an amount of cold water in a glass container. Carefully measure the volume, mass, and temperature of the water and record the results. Place the container onto a hotplate and heat for one or two minutes and repeat all measurements, recording the values. Place the container back on the hotplate and heat until the water boils. Repeat all measurements, recording the values. While this process is ongoing, invite discussion and observations.		
Required Submissions	Students work in pairs, collaborating on an individual experiment for each student. At least twenty observations, one data table, and one graph from each student are required. An original, completed HBL worksheet is required from each student. Graphs and data tables may be attached to		

Figure C.50. HBL Laboratory HT 3 - page 1

	completed HBL worksheets. **Note:** Graphs and data tables (and the information contained in them) count as *single* observations!
That's odd...	It is difficult to accurately measure the volume of salt or sugar. The amount of salt that will dissolve in water is changeable. Temperature seems easily variable and difficult to conserve.
Food for Thought	How can the uncertainty of the measuring devices be estimated? Can a graph indicate conservation of a quantity? Is it possible to make a principle into a law by expanding the focus on the system under study?

Figure C.51. HBL Laboratory HT 3 - page 2

Physics 1313
HT 4 Experiment Outline

<table>
<tr><th colspan="4">HT 4 - Heating Liquids</th></tr>
<tr><td>Background</td><td colspan="3">Recall that variables under study may remain constant or change in value. Detailed tests under varied conditions allow us to conclude which ones are actually conserved and which ones aren't.

During thermal interactions, it is interesting to note that hot things usually cool down while cold things generally increase in temperature; we never see the opposite situation occur by itself. However, they both eventually reach the same final temperature - we call this state of equal temperatures that results from a thermal interaction thermal equilibrium or just equilibrium. 'Equilibrium' typically means 'balance', which is appropriate in this analogy - the two objects interact until their temperatures 'balance' or are equal. Both objects then remain at that temperature until they interact with the environment or other objects. This seems to indicate that the two objects are exchanging something that causes temperature.

When two objects interact thermally, we say they exchange heat. Heat is a property an object has that relates to temperature - the more heat an object has, the larger its temperature. The larger the temperature of an object, the more likely it is to interact with other objects. Heat may be thought of in a manner analogous to money in the sense that it is easily exchanged and the amount possessed represents the ability to interact (the ability to acquire things, or 'buying power'). Unfortunately, heat is one of those properties of an object that is not readily visible, and its presence and amount must be inferred from other (indirect) measurements. The good news is that, since the presence of heat influences an object's temperature, the temperature of the object tells us something about the amount of heat the object possesses. This is akin to seeing a person that has many things (nice car, cool house, fancy watch, whatever) and deducing that he has a lot of money. Interestingly, since objects that interact reach equilibrium, they have the same temperature and therefore exchange no heat.

Therefore, when an object 'heats up' another, we are really implying that they are exchanging heat and their temperatures change as a result of the interaction. The ultimate goal of this module is to develop a model allowing us to infer how heat is exchanged by objects and the effects of this interchange.</td></tr>
<tr><td rowspan="4">Equipment</td><td>Celsius thermometers</td><td>waterproof containers: glass, metal</td><td>hotplate</td></tr>
<tr><td>graph paper</td><td>water</td><td>stopwatch</td></tr>
<tr><td>electronic scales</td><td>graduated cylinders</td><td>syrup</td></tr>
<tr><td>cooking oil</td><td>salt</td><td>sugar</td></tr>
<tr><td>Experimental Setup</td><td colspan="3">Each group should have the above items readily available.

Please do not mix ANYTHING with either the syrup or cooking oil so they may be reused!</td></tr>
</table>

Figure C.52. HBL Laboratory HT 4 - page 1

Initiating Event	Place equal masses of room-temperature water into two differently-sized glass containers. Carefully measure the volume, mass, and temperature of both and record the results. Place unequal masses of room-temperature water into same-sized glass containers. Carefully measure the volume, mass, and temperature of both and record the results. Place all four containers onto a hotplate and heat for four minutes. Solicit predictions and observations. Using caution with the now hot container and fluids, repeat all measurements, recording the values. While this heating process is ongoing, measure the temperature at thirty-second intervals. Invite discussion and observations.
Required Submissions	Students work in pairs, collaborating on an individual experiment for each student. At least twenty observations, one data table, and one graph from each student are required. An original, completed HBL worksheet is required from each student. Graphs and data tables may be attached to completed HBL worksheets. **Note:** Graphs and data tables (and the information contained in them) count as *single* observations!
That's odd...	The type of container seems to have an influence on the rate of heating. The amount of salt that will dissolve in water changes with increasing temperature. Syrup becomes much more 'fluid' upon heating.
Food for Thought	How does the mass of an object change upon heating? How can the amount of heat an object gains or loses be calculated? Does the size of container, type of container, mass of the system, or volume of the system have anything to do with the heating rate?

Figure C.53. HBL Laboratory HT 4 - page 2

Physics 1313
HT 5 Experiment Outline

HT 5 - Mixing Water 1			
Background	Recall from previous experiments and background discussions: • variables under study may remain constant or change in value • the function of a styrofoam container is to isolate the system under study • thermally interacting objects exchange heat until they reach equilibrium • the ultimate goal of this module is to develop a model allowing us to infer how heat is exchanged by objects and the effects of this interchange		
Equipment	Celsius thermometers	waterproof containers: glass, styrofoam	hotplate
	graph paper	hot water (approximately 60 °C - 80 °C)	cold water (approximately 10 °C)
	electronic scales	graduated cylinders	stopwatch
Experimental Setup	Each group should have the above items readily available. **Please limit your investigations in this lab to equal amounts of water!**		
Initiating Event	Obtain equal masses of room-temperature water and hot water in two styrofoam containers. **Important**: the amount of water used should be *less than half* the volume of the cup! Carefully measure the mass and temperature of both and record the results. Indicate the intention to pour the water together in the cup containing the hot water. Solicit predictions and observations. Using caution with the containers and fluids, pour the cold water into the hot water cup and *immediately* repeat all measurements, beginning with the temperature (use the hot thermometer). Record these values. Invite discussion and observations.		
Required Submissions	Students work in pairs, collaborating on an individual experiment for each student. At least twenty observations and one data table from each student are required. An original, completed HBL worksheet is required from each student. Graphs and data tables may be attached to completed HBL worksheets. **Note:** Graphs and data tables (and the information contained in them) count as *single* observations!		
That's odd...	Does stirring have an effect on temperature? Will the act of pouring change the temperature? The results of this experiment become more reliable with increasing amounts.		
Food for Thought	Is there a rule that will allow the prediction of the final equilibrium temperature of the mixture? Why use the styrofoam containers? Which variables seem to have the most effect on the final temperature?		

Figure C.54. HBL Laboratory HT 5 - page 1

Physics 1313
HT 6 Experiment Outline

<table>
<tr><th colspan="4">HT 6 - Mixing Water 2</th></tr>
<tr><td>Background</td><td colspan="3">Recall from previous experiments and background discussions:
• variables under study may remain constant or change in value
• the function of a styrofoam container is to isolate the system under study
• thermally interacting objects exchange heat until they reach equilibrium
• we have a model for how two equal amounts of water interact to yield an equilibrium temperature
• the ultimate goal of this module is to develop a model allowing us to infer how heat is exchanged by objects and the effects of this interchange
• a calorie is defined as the amount of heat necessary to change the temperature of one gram of water by one degree Celsius
By now, it is clear that water at a certain temperature has some amount of heat that depends on the amount (mass) of water. This heat may be exchanged with another amount of water at some different temperature. The amount of heat some water has may be difficult to calculate, since we would have to add up all of the heat necessary to raise the water to its present temperature. Fortunately, we know that the water will only exchange heat with objects that have different temperatures, and will stop exchanging heat when the temperatures become equal. This allows us to think of the heat exchanged not as an exchange of the total amount of heat, but rather as the difference in the heats of the water amounts.

We define the heat capacity of an object as the amount of heat necessary to change its temperature by one degree Celsius. Note that we are indicating that the entire object changes temperature - every gram of the object's mass changes temperature by one degree Celsius. Using the calorie definition, we can determine the heat capacity of an amount of water whose mass is m grams. The calorie definition indicates that the addition or subtraction of one calorie will change the temperature of one gram of water by one degree Celsius. Therefore, we have to count the number of grams in the amount m of water that we have, as each will require one calorie to change temperature by one degree Celsius. As there are m grams, the heat capacity of the amount of water is m calories.

Heat capacity may also be found using graphs - if the heat gained by an object versus the temperature change the object experiences is plotted, the slope of the graph will be the object's heat capacity.</td></tr>
<tr><td rowspan="3">Equipment</td><td>Celsius thermometers</td><td>waterproof containers: glass, metal, styrofoam</td><td>hotplate</td></tr>
<tr><td>graph paper</td><td>hot water (approximately 60 °C - 80 °C)</td><td>cold water (approximately 10 °C)</td></tr>
<tr><td>electronic scales</td><td>graduated cylinders</td><td>stopwatch</td></tr>
<tr><td>Experimental</td><td colspan="3">Each group should have the above items readily available.</td></tr>
</table>

Figure C.55. HBL Laboratory HT 6 - page 1

Setup	**Please limit your investigations in this lab to unequal amounts of water!**
Initiating Event	Obtain unequal masses of room-temperature water and hot water in two styrofoam containers. **Important**: the total amount of water used should be *less than* the volume of one cup! Carefully measure the mass and temperature of both and record the results. Indicate the intention to pour the water together in the cup containing the hot water. Solicit predictions and observations. Using caution with the containers and fluids, pour the cold water into the hot water cup and *immediately* repeat all measurements, beginning with the temperature (use the hot thermometer). Record these values. Invite discussion and observations.
Required Submissions	Students work in pairs, collaborating on an individual experiment for each student. At least twenty observations and one calculation of an equilibrium temperature of a mixture of unequal masses of water using the table method outlined in the lecture from each student are required. An original, completed HBL worksheet is required from each student. Graphs and data tables may be attached to completed HBL worksheets. **Note:** Graphs and data tables (and the information contained in them) count as *single* observations!
That's odd...	Why use the *hot* thermometer? The equilibrium temperature seems to be more close to the large mass's temperature. Proportional mixing seems easiest way to get some idea of the underlying pattern here.
Food for Thought	Is there a rule that will allow the prediction of the final equilibrium temperature of the mixture? Can the mixture's equilibrium temperature be determined using proportions? Which variables seem to have the most effect on the final temperature?

Figure C.56. HBL Laboratory HT 6 - page 2

Physics 1313
HT 7 Experiment Outline

HT 7- Specific Heat 1			
Background	Recall from previous experiments and background discussions: • the function of a styrofoam container is to isolate the system under study • thermally interacting objects exchange heat until they reach equilibrium • we have a model for how two equal amounts of water interact to yield an equilibrium temperature • a **calorie** is defined as the amount of heat necessary to change the temperature of one gram of water by one degree Celsius • the **heat capacity** of an object is the amount of heat necessary to change the temperature of the entire object by one degree Celsius • if the heat gained by an object versus the object's temperature change is plotted, the slope of the graph will be the object's heat capacity • the ultimate goal of this module is to develop a model allowing us to infer how heat is exchanged by objects and the effects of this interchange We have noticed that, according to the definition of a calorie, when one gram of water changes temperature by one degree Celsius there is an exchange of one calorie of heat between the water and some other object. So far, we have only investigated the behavior of water. Other materials may or may not behave the same way. We define the **specific heat capacity** or, more commonly, the **specific heat** of an object as the amount of heat necessary to change the temperature of one gram of that material by one degree Celsius. Note that we are *not* indicating that the *entire* object changes temperature, but that a single gram of the object's mass changes temperature by one degree Celsius.		
Equipment	Celsius thermometers	waterproof styrofoam containers	hotplate
	graph paper	hot water (approximately 60 °C - 80 °C)	cold water (approximately 10 °C)
	electronic scales	various regular and irregular aluminum objects	thread
Experimental Setup	Each group should have the above items readily available.		
Initiating Event	Obtain an aluminum object of approximately 20 g mass. Measure the mass and record the result. Using thread, suspend the aluminum object in hot water for at least one minute. Meanwhile, obtain an amount of hot water having a mass equal to the aluminum object in a styrofoam container and record its mass. Obtain two styrofoam containers, each having 50 g of cold water. **Important**: the total amount of water used should be *less than* the volume of one cup! Carefully measure the masses and temperatures of both amounts of cold water and record the results. Indicate the intention to place each object into a different container of water. Solicit predictions and		

Figure C.57. HBL Laboratory HT 7 - page 1

	observations. Using caution with the containers, objects, and fluids, measure the temperature of the hot water immediately prior to removing the aluminum object. Place the object into one container of cold water as quickly as possible and measure the equilibrium temperature. Repeat for the mass of hot water. Record all data values. Invite discussion and observations.
Required Submissions	Students work in pairs, collaborating on an individual experiment for each student. At least twenty observations, one graph, one data table, and one calculation of an object's specific heat from each student are required. An original, completed HBL worksheet is required from each student. Graphs and data tables may be attached to completed HBL worksheets. **Note:** Graphs and data tables (and the information contained in them) count as *single* observations!
That's odd...	Different objects change the water's temperature differently. The length of time between the removal of the object from the hot water bath and placement in the cool water has a measurable effect on the equilibrium temperature. The objects do not alter the cold water's temperature by the same amount as water.
Food for Thought	Is there a rule that will allow the prediction of the final equilibrium temperature of the mixture? Can the combination's equilibrium temperature be determined using proportions? Which materials seem to have the most effect on the final temperature? How can the amount of heat exchanged by the water and the object be determined?

Figure C.58. HBL Laboratory HT 7 - page 2

Physics 1313
HT 8 Experiment Outline

<table>
<tr><th colspan="4">HT 8 - Specific Heat 2</th></tr>
<tr><td>Background</td><td colspan="3">Recall from previous experiments and background discussions:
• the function of a styrofoam container is to isolate the system under study
• thermally interacting objects exchange heat until they reach equilibrium
• we have a model for how two equal amounts of water interact to yield an equilibrium temperature
• a calorie is defined as the amount of heat necessary to change the temperature of one gram of water by one degree Celsius
• the heat capacity of an object is the amount of heat necessary to change the temperature of the entire object by one degree Celsius
• the specific heat of an object is the amount of heat necessary to change the temperature of one gram of that object by one degree Celsius
• if the heat gained by an object versus the object's temperature change is plotted, the slope of the graph will be the object's heat capacity
• the ultimate goal of this module is to develop a model allowing us to infer how heat is exchanged by objects and the effects of this interchange
• we have an extended model for how two different objects interact to yield an equilibrium temperature
We have noticed that, according to the definition of a calorie, when one gram of water changes temperature by one degree Celsius there is an exchange of one calorie of heat between the water and some other object. So far, we have only investigated the behavior of water. In the past lab (HT 7), we discovered that materials different from water do not behave exactly as water, but in a characteristic way for that material.</td></tr>
<tr><td rowspan="3">Equipment</td><td>Celsius thermometers</td><td>waterproof styrofoam containers</td><td>hotplate</td></tr>
<tr><td>graph paper</td><td>hot water (approximately 60 °C - 80 °C)</td><td>cold water (approximately 10 °C)</td></tr>
<tr><td>electronic scales</td><td>various non-porous, regular and irregular objects of differing material composition (none should be soluble in water, and all should have melting points above 100 °C)</td><td>thread</td></tr>
<tr><td>Experimental Setup</td><td colspan="3">Each group should have the above items readily available.</td></tr>
<tr><td>Initiating Event</td><td colspan="3">Obtain two objects of differing materials that have the same mass. Measure the mass of each and record the results. Using thread, suspend the objects in the same hot water reservoir for at least one minute. Meanwhile, obtain two equal amounts of cold water in styrofoam containers and record</td></tr>
</table>

Figure C.59. HBL Laboratory HT 8 - page 1

	their masses and temperatures. **Important**: each object should be able to be fully submerged in the amount of water used, and the total amount of water used should be *less than* half the volume of one cup! Indicate the intention to place each object into a different container of water. Solicit predictions and observations. Using caution with the containers, objects, and fluids, measure the all water temperatures immediately prior to removing the objects. Place each object into a container of cold water as quickly as possible and measure the equilibrium temperatures of both systems. Record all data values. Invite discussion and observations.
Required Submissions	Students work in pairs, collaborating on an individual experiment for each student. At least twenty observations, one graph, one data table, and one calculation of an object's (not aluminum!) specific heat from each student are required. An original, completed HBL worksheet is required from each student. Graphs and data tables may be attached to completed HBL worksheets. **Note:** Graphs and data tables (and the information contained in them) count as *single* observations!
That's odd...	Different materials change the water's temperature differently. Some objects seem to "hold onto" their heat more than others. Water seems pretty effective in changing other object's temperatures.
Food for Thought	Is there a rule that will allow the prediction of the final equilibrium temperature of the mixture? Can the combination's equilibrium temperature be determined using proportions? Which materials seem to have the most effect on the final temperature? How can the amount of heat exchanged by the water and the object be determined?

Figure C.60. HBL Laboratory HT 8 - page 2

Physics 1313
HT 9 Experiment Outline

HT 9 - Phase Changes 1	
Background	Recall from previous experiments and background discussions: • the function of a styrofoam container is to isolate the system under study • thermally interacting objects exchange heat until they reach equilibrium • the heat exchanged by an object and an amount of water may be calculated given data regarding the changes the water experiences • a **calorie** is defined as the amount of heat necessary to change the temperature of one gram of water by one degree Celsius • the **heat capacity** of an object is the amount of heat necessary to change the temperature of the entire object by one degree Celsius • the **specific heat** of an object is the amount of heat necessary to change the temperature *of one gram* of that object by one degree Celsius • we have an extended model for how two different objects interact to yield an equilibrium temperature In general, materials may experience different states - they may be solid, liquid, or gaseous. These varying states we refer to as **phases**. Some materials may have several varieties of a given phase - some metals, for instance, have many different crystalline solid forms (and therefore many different solid phases). Clearly each of a material's states are correlated with the amount of heat they possess: water may be heated and caused to change phase from liquid to vapor (gas), ice may be heated and caused to become liquid, or ice may immediately become water vapor (under the correct circumstances). Each of the system's change in phase is called a **phase transition**. We know from everyday experience that ice (solid water) added to liquid water will cool the liquid at the expense of the amount of ice. That is, the ice will melt, becoming liquid water and reducing the temperature of the water as a consequence. This behavior implies that the ice is receiving heat from its surrounding environment. This heat accomplishes two distinct things: it melts the ice and then heats the newly-melted water to the temperature of the remaining water. We conceptualize this exchange of heat by breaking it into two distinct components. The heat necessary to change the phase of *one gram* of the substance *without* changing the material's temperature is called a **latent heat**, while we already understand the additional heat necessary to alter the temperature of the material after its phase has been changed. The word 'latent' is used to imply that the heat is "hidden" - added heat does not always cause a temperature change. Usually, we look for temperature changes to imply a heat exchange between objects, but this situation shows us that heat exchange is not always detectable by this method. A material has one latent heat for each possible combination of phase changes. For instance, water has three latent heats: the **latent heat of fusion** (for solid-liquid transitions), the **latent heat of vaporization** (for liquid-gas transitions), and the **latent heat of sublimation** (for solid-gas transitions). Other materials may have fewer or many more latent heats. Latent heats are given the symbol **L**, usually subsripted with an abbreviation of the latent heat being considered. Thus, $\mathbf{L_{fusion}}$ refers to the latent heat of fusion, while $\mathbf{L_{vap}}$ indicates the latent heat of vaporization. Latent heats are measured in calories. We can see the presence of a phase change on a graph of temperature versus heat added -

Figure C.61. HBL Laboratory HT 9 - page 1

	generally, as heat is added the temperature increases. However, on some graphs this behavior is replaced in certain regions where the temperature remains constant as heat is added. In this region, a phase change is occurring. Another use for graphs would be in the determination of the latent heat's numerical value. The slope of a graph of heat added versus mass of material induced to change phase is the latent heat for that phase transition.		
Equipment	Celsius thermometers	waterproof styrofoam containers	hotplate
	graph paper	a supply of ice cubes (2 - 5 kg)	water
	electronic scales	funnels	
Experimental Setup	Each group should have the above items readily available.		
Initiating Event	Obtain two styrofoam containers containing 50g of room temperature water. Measure and record all masses and temperatures, and the temperature of the reservior containing the ice. Indicate the intention to place approximately 50 g of ice into one container of water and double that amount into the other container. Solicit predictions and observations. **Important**: The styrofoam container should be large enough to accomodate the addition of a significant amount of ice. Place the ice into the containers. Invite discussion and observations. Speculate aloud: "Is there any way to determine how much ice melted?"		
Required Submissions	Students work in pairs, collaborating on an individual experiment for each student. At least twenty observations, one data table, and one calculation of the latent heat of fusion for water from each student are required. An original, completed HBL worksheet is required from each student. Graphs and data tables may be attached to completed HBL worksheets. **Note:** Graphs and data tables (and the information contained in them) count as *single* observations!		
That's odd...	Water freezes at 0 °C, right? Where does the water on the outside of the cold containers come from? Ice changes color as it melts and releases bubbles.		
Food for Thought	How will the addition of latent heats alter the table method? Can the amount of ice melted in this thermal interaction be determined? Can water and ice exist simultaneously at 0 °C?		

Figure C.62. HBL Laboratory HT 9 - page 2

Physics 1313
HT 10 Experiment Outline

HT 10 - Phase Changes 2			
Background	Recall from previous experiments and background discussions: • the function of a styrofoam container is to isolate the system under study • thermally interacting objects exchange heat until they reach equilibrium • the heat exchanged by an object and an amount of water may be calculated given data regarding the changes the water experiences • a **calorie** is defined as the amount of heat necessary to change the temperature of one gram of water by one degree Celsius • the **heat capacity** of an object is the amount of heat necessary to change the temperature of the entire object by one degree Celsius • the **specific heat** of an object is the amount of heat necessary to change the temperature *of one gram* of that object by one degree Celsius • the heat necessary to change the phase of *one gram* of the substance *without* changing its temperature is called a **latent heat** • we have an extended model for how two different objects interact to yield an equilibrium temperature • the slope of a graph of heat added versus mass of material induced to change phase is the latent heat for that phase transition		
Equipment	Celsius thermometers	waterproof metal containers	hotplate
	graph paper	water	hot pads
	electronic scales	saran wrap	rubber bands
Experimental Setup	Each group should have the above items readily available.		
Initiating Event	Obtain two metal containers containing 50g and 500g of room temperature water. Measure and record all masses and temperatures. Place a thermometer into the larger amount of water, and cover that container with saran wrap held in place with a rubber band. Place both containers close to one another on an aggressively set hot plate. Indicate the intention to leave both containers on the hotplate until the smaller container boils for one minute. Solicit predictions and observations. **Important**: The metal containers will get quite hot, so use hotpads and other protective gear! Measure the mass of the water in each container after heating (use hot pads!) and the final temperature of the larger container's water. Invite discussion and observations. Speculate aloud: "How much heat did each container receive, and what did that heat accomplish?"		
Required Submissions	Students work in pairs, collaborating on an individual experiment for each student. At least twenty observations, one data table, one graph, and one calculation of the latent heat of vaporization for water from each student are required. An original, completed HBL worksheet is required from		

Figure C.63. HBL Laboratory HT 10 - page 1

	each student. Graphs and data tables may be attached to completed HBL worksheets. **Note:** Graphs and data tables (and the information contained in them) count as *single* observations!
That's odd...	Why does the saran wrap bulge outwards when the water is heated? Where does the water in the smaller container go? Is there a compelling reason to use metal containers?
Food for Thought	How will the addition of latent heats alter the table method? Can the amount of water evaporated in this thermal interaction be determined? Can water and steam (water vapor) exist simultaneously at 100 °C?

Figure C.64. HBL Laboratory HT 10 - page 2

C.6.2 HBL Class Activities

The 3 HBL Heat and Temperature class activities appear in the following Figures.

HBL HT Lecture 1

In this module, we are concerned with finding a model that will allow us to predict the final equilibrium temperatures of a thermally interacting system. We discovered two different temperature scales commonly used in science, both based on physical phenomena. A liquid's **boiling point** is the temperature where the liquid is fully boiling (not just bubbling). The **freezing point** of a fluid is that temperature where the liquid freezes solid. For water under the particular reference conditions of sea-level altitude and exactly one atmospheric pressure ("standard temperature and pressure", or STP), the boiling point is 100 ºC or 212 ºF, while the freezing point is 0 ºC or 32 ºF. The "size" of one degree Celsius is 1.8 times larger than one Fahrenheit degree, and the two scales may be related using the following two formulae:

$$^{\circ}C = \tfrac{5}{9}\left(^{\circ}F - 32\right) \quad \text{and} \quad ^{\circ}F = \tfrac{9}{5}{}^{\circ}C + 32$$

We have discovered that instruments have accuracy, precision, and uncertainty. All readings taken from a thermometer should be in degrees Celsius and estimated to the nearest 0.1 ºC for the remainder of the module. We have determined that, for a system that is physically closed, mass is conserved and volume is not.

In the last lab we mixed fluids having different temperatures in Styrofoam containers. More accurate results were obtained by pouring the lower temperature sample into the higher temperature sample. We will follow this procedure for the remainder of the HT module. We also observed that when equal masses of water were mixed under these controlled circumstances, the equilibrium temperature was the average temperature. The model developed must be able to explain why this is so, and account for variations in behavior.

Development of the Heat Transfer Model:

In the paragraphs below, definitions and critical pieces of the model will be presented in **bold** typeface.

Two or more objects (the **system**) placed in physical contact can alter one another's temperature by exchanging heat. **The amount of heat an object has determines its temperature** – more heat implies more temperature. **If the objects are not initially at the same temperature, they will exchange heat until they reach thermal equilibrium** (their final temperatures are the same). The loss of heat by the hot object lowers its temperature, while the gain in heat by the colder object will result in an increase in its temperature. This reasoning shows us a way to conceptualize this process with a simple relationship:

(Heat lost by hot object) = (Heat gained by cold object)

Notice that here we are assuming that there is nowhere else for the heat to travel – we have allowed the system no interaction with external objects (like the atmosphere, the tabletop, or anything else). This is an idealization, but one that can be closely approximated using calorimetry. We do this by using Styrofoam containers and measuring the temperatures immediately before and after mixing to insure no heat escapes to objects outside the system. **We have also assumed that there have been no changes in the physical form of the substance –** no melting, boiling, or other changes. All that is needed now is some way of determining the heat exchanged by the two objects and a method for determining the gain or loss of temperature associated with the change in heat.

In the metric system, we define heat in units called calories. **One calorie is the amount of heat needed to change the temperature of one gram of water by one degree Celsius**. Thus, if one gram of water received five calories the temperature would rise by five degrees Celsius. **If several grams of water receive or lose an amount of heat, they share the change in heat equally since they are in contact with one another and will interact until they all have the same equilibrium temperature.** If three grams of water lost a total of twelve calories, each gram loses the same four calories of heat, resulting in a loss of four degrees Celsius. Note that at this point, we only have information for water – we will have to expand our model to include other materials. Also note that we can calculate the amount of heat *exchanged*, not the *total* amount of heat an object possesses.

Figure C.65. HBL HT Lecture 1 - page 1

Thus, our general strategy is this: **find the number of calories gained or lost by <u>each gram</u> of every object in the system and relate that to the temperature <u>change</u> of those objects using the calorie definition.**

This definition of calorie is not the same as the Calorie you may be used to seeing on the 'Nutritional Information' panel on most food products, but the two are related. One Calorie (notice the capital "C") is one thousand calories, sometimes called a "kilocalorie". We will avoid any confusion by using ONLY calories as defined above. Incidentally, there are other common units for heat. The **British Thermal Unit** (BTU) is the amount of heat required to change the temperature of one pound of water by one degree Fahrenheit.

Sometimes the determination of how each gram gains or loses heat is most easily summarized in a table. An example table is shown below. Some of the cells within the table may only become important as we increase the sophistication of our model. It is recommended that you show the first row of data in your table as the system *before* any heat is transferred. Thus, we would have the mass of the hot and cold objects and their temperatures while the transferred heat is zero. Then choose an amount of heat to be transferred and calculate how the temperatures change as a result. Continue doing this procedure until the final temperatures of the hot and cold objects are equal. This **table method** is rather general and is useful for a variety of circumstances.

Transferred Heat (calories)	HOT object Mass (grams)	Heat lost by each HOT gram (calories)	HOT object Temperature (ºC)	COLD object Mass (grams)	Heat gained by each COLD gram (calories)	COLD object Temperature (ºC)

<u>Important Note:</u> Students typically have the most difficulty in choosing the amount of heat to be transferred in each row when using the table method. The best rule of thumb is to **choose a number that is easy to calculate**! If the *most* convenient number results in a temperature change that is too small (resulting in many rows in the table before anything significant happens), try multiplying that convenient amount of heat transferred by 10 or 100 to cause the temperature to change more quickly. If you do this, don't forget to recalculate the new temperature change for each gram! This same trick may also be used to reduce the size of a temperature change, but division would be used instead of multiplication.

<u>Group-work Examples:</u>

#1 What is the equilibrium temperature of 4 g of water at 50 ºC mixed with 4 g of water at 12 ºC?

#2 How much heat is required to change the temperature of 20 g of water by 4 ºC?

#3 Find the heat transferred when 10 g of water at 5 ºC is mixed with 10 g of water at 17 ºC. Calculate this using a 'mathematical' model and using the table method.

#4 Is this model generalizable – that is, is it capable of being extended to unequal masses of water?

#5 Find the equilibrium temperature of 20 g of water at 30 ºC mixed with 50 g of water at 70 ºC. Calculate this using a 'mathematical' model and using the table method.

#6 Can you use this model to determine the heat lost to the environment when water is mixed in metal containers?

<u>HT Lecture 1 Homework Questions:</u>

1) Why do temperature changes for each gram of water not get added but heat transfers do?

2) Why is the equilibrium temperature of equal masses of water the average of the initial temperatures? Explain your answer in detail, using an explained example. Answers must utilize the model of heat outlined above.

3) Why haven't we included the containers in our analysis? They are touching the fluids and should either supply heat or remove heat when the fluids change temperature. Provide at least two reasons for ignoring them.

4) Is heat a conserved quantity? If so, what are the conditions for its conservation? If not, why not?

Figure C.66. HBL HT Lecture 1 - page 2

HBL HT Lecture 2

In the last lab, it was found that aluminum does not behave the same as water when transferring heat. In fact, the amount of heat "stored" by aluminum is much less than an equal mass of water. We have seen that the specific heat of a material has something to do with the amount of heat a material can transfer.

Recall that the **Heat Capacity** of an object is the amount of heat necessary to change the temperature of the entire object by one degree Celsius. We assign the variable **K**, measured in calories per degree Celsius, to heat capacity. In general, we denote an amount of heat transferred between two objects as **ΔQ**, measured in calories.

Specific Heat is defined as the amount of heat needed to change the temperature of one gram of a material by one degree Celsius. Specific heat is usually given the variable name **c**, and is measured in units of calories per gram per degree Celsius and written $\frac{cal}{g \cdot {}^{\circ}C}$. If the specific heat of Aluminum is 0.21 $\frac{cal}{g \cdot {}^{\circ}C}$, it takes 0.21 calories to change the temperature of 1 g of aluminum by 1 ºC. When explaining reasoning in problems, be sure to explain the reasons behind the mathematics used. Thus, when changing the temperature of 1 g of aluminum by 17 ºC, it takes 17 * (0.21) calories.

Further Development of the Heat Transfer Model:

In the paragraphs below, definitions and critical pieces of the model will be presented in **bold** typeface.

Recall the major points in the previous model:

- **The amount of heat an object has determines its temperature – more heat implies more temperature.**
- **If objects are in physical contact but not initially at the same temperature, they will exchange heat until they reach thermal equilibrium.**
- **(Heat lost by hot object) = (Heat gained by cold object)**
- **We assume that there is nowhere else for the heat to travel, and that there have been no changes in the physical form of the substance.**
- **If several grams of water receive or lose an amount of heat, they share the change in heat equally since they are in contact with one another and will interact until they all have the same equilibrium temperature.**
- Our general strategy is this: **find the number of calories gained or lost by each gram of every object in the system and relate that to the temperature change of those objects using each material's specific heat value.**
- **We stop the procedure when the objects reach equilibrium (the temperatures are equal).**

The major change the model needs to address is that now **different materials may have different specific heats: that is, it may not take exactly one calorie to change the temperature of one gram of the material by one degree Celsius**. Thus, we need more columns in the table method to allow for this calculation. **Notice that here we are assuming that the material's specific heat is a constant value.**

HEAT		HOT Object					COLD Object				
This step (cal)	Total (cal)	Mass (g)	SH (cal/gºC)	1g Heat loss (cal)	1g Temp. change (ºC)	Temp. (ºC)	Mass (g)	SH (cal/gºC)	1g Heat gain (cal)	1g Temp. change (ºC)	Temp. (ºC)

Figure C.67. HBL HT Lecture 2 - page 1

Important Note (Reminder): Students typically have the most difficulty in choosing the amount of heat to be transferred in each row when using the table method. This situation is complicated by the differing specific heats of each material, typically causing the numbers to "not work out nicely". Knowing that this will be a problem at the beginning, the best rule of thumb is to choose a number that is easy to calculate for one of the two materials (typically the hot material). Don't forget that you may choose to multiply that convenient amount of heat by 10 or 100 to cause the temperature to change more quickly. If you do this, don't forget to recalculate the new temperature change for each gram! This same trick may also be used to reduce the size of a temperature change, but division would be used instead of multiplication.

Mathematical Extension of the Heat Transfer Model:
If an object of mass **m** and specific heat **c** accepts some amount of heat **ΔQ** and experiences a temperature change **ΔT**, the interrelation among the variables may be expressed:

$$\Delta Q = mc\Delta T$$

The heat capacity is also related to the mass and specific heat:

$$K = mc$$

Note that, if the heat lost by the hot object is entirely given to the cold object as our model suggests:

$$\begin{pmatrix}\text{Heat lost} \\ \text{by Hot object}\end{pmatrix} = \begin{pmatrix}\text{Heat gained} \\ \text{by Cold object}\end{pmatrix}$$

$$m_{hot} c_{hot} \Delta T_{hot} = m_{cold} c_{cold} \Delta T_{cold}$$

Given that the temperature change **ΔT** is the difference of the beginning and ending temperatures and that both objects end up in thermal equilibrium with one another, the equilibrium temperature may be solved algebraically:

$$T_{EQ} = \frac{m_{hot} c_{hot} T_{hot} + m_{cold} c_{cold} T_{cold}}{m_{hot} c_{hot} + m_{cold} c_{cold}}$$

Proportional Reasoning:
Another method for determining how the objects will alter their temperatures when placed in physical contact is called Proportional Reasoning. It utilizes known relationships among the physical quantities to arrive at the solution to a question without using algebra.

Group-work Examples:

#1 What is the equilibrium temperature of 14 g of water at 50 ºC mixed with 32 g of water at 12 ºC?

#2 How many calories are needed to change the temperature of 65 g of carbon by 17 ºC?

#3 If 40 g of aluminum at 50 ºC is mixed with 15 g of water at 12 ºC, what is the equilibrium temperature?

#4 What is the equilibrium temperature of 24 g of aluminum at 75 ºC is placed in contact with 18 g of steel (iron) at 5 ºC?

#5 A heat transfer of 120 calories are required to change the temperature of 24 g of a material by 10 ºC. If 280 calories are delivered to 40 g of the same material, find the temperature change of the material.

#6 If 20 calories are required to change the temperature a stone by 200 ºC, how much heat would raise the temperature of one million times as much stone by 5 ºC?

Figure C.68. HBL HT Lecture 2 - page 2

HBL HT Lecture 3

<u>Definitions and Important Information:</u>

- The **boiling point** of a liquid is the temperature where the liquid is fully boiling, and the **freezing point** of a fluid is the temperature where the liquid freezes solid.
- The Fahrenheit and Celsius scales are related by the formulae: $^{\circ}C = \frac{5}{9}\left(^{\circ}F - 32\right)$ and $^{\circ}F = \frac{9}{5}{}^{\circ}C + 32$
- For a system that is physically closed, mass is conserved while volume is not.
- One **calorie** is the amount of heat needed to change the temperature of one gram of water by 1 ºC.
- One Calorie (notice the capital "C") is one thousand calories, sometimes called a "kilocalorie".
- The **British Thermal Unit** (BTU) is defined as the amount of heat required to change the temperature of one pound of water by one degree Fahrenheit.
- An object's **Heat Capacity** is the amount of heat necessary to change the temperature of the entire object by 1 ºC. We assign heat capacity the variable **K**, measured in calories per degree Celsius ($\frac{cal}{^{\circ}C}$).
- **Specific Heat** is defined as the amount of heat needed to change the temperature of one gram of a material by 1 ºC. Specific heat is usually given the variable name **c**, and is measured in units of calories per gram per degree Celsius, written $\frac{cal}{g \cdot {}^{\circ}C}$.
- The varying states of matter are referred to as **phases**, and include solids, liquids, or gases.
- Each of the system's change in phase is called a **phase transition**. A material has one latent heat for each possible combination of phase transitions. Three of the most commonly encountered latent heats are: the **latent heat of fusion** ($\mathbf{L_f}$, for solid-liquid transitions), the latent heat of vaporization ($\mathbf{L_{vap}}$, for liquid-gas transitions), and the latent heat of sublimation ($\mathbf{L_{sub}}$, for solid-gas transitions).
- The heat necessary to change the phase of one gram of the substance *<u>without changing its temperature</u>* is called a **latent heat**. Latent heats, denoted as **L**, are measured in calories per gram.

<u>Heat Transfer Model:</u>

The major points in the model:

- **The heat an object has determines its temperature – more heat implies more temperature.**
- **If objects are in physical contact but not initially at the same temperature, they will exchange heat until they reach thermal equilibrium.**
- **We assume no losses: thus (Heat <u>lost</u> by hot object) = (Heat <u>gained</u> by cold object).**
- **We assume that a material's specific heat is a constant value for any phase.**
- **If there are no phase changes and several grams receive or lose heat, they share the heat equally.**
- **During a phase transition, all grams of the material DO NOT share the heat equally – we model this by changing the phase of a single gram at a time.**
- **The temperature of a material undergoing a phase transition cannot change until every gram of the material has changed phase.**
- **We stop the procedure when the objects reach equilibrium (the temperatures are equal).**

HEAT		HOT Object						COLD Object					
This step (cal)	Total (cal)	Phase 1 Mass (g)	Phase 2 Mass (g)	SH or L (cal/gºC, cal/g)	1g Heat loss (cal)	1g Temp. change (ºC)	Temp. (ºC)	Phase 1 Mass (g)	Phase 2 Mass (g)	SH or L (cal/gºC, cal/g)	1g Heat gain (cal)	1g Temp. change (ºC)	Temp. (ºC)

<u>Important Note (Reminder):</u> The best rule of thumb for determining the heat to be transferred is to choose a number that is easy to calculate for one of the two materials (typically the hot material). **If one of the materials is undergoing a phase transition, choose multiples of the latent heat for that phase transition until every gram has changed phase.** Don't forget that you may choose to multiply some convenient amount of heat by 10 or 100 to cause the temperature to change more quickly.

Figure C.69. HBL HT Lecture 3 - page 1

Mathematical Extensions of the Heat Transfer Model (assuming no phase transitions):
If an object of mass **m** and specific heat **c** accepts some amount of heat **ΔQ** and experiences a temperature change **ΔT**, the interrelation among the variables may be expressed:

$$\Delta Q = mc\Delta T$$

The heat capacity is also related to the mass and specific heat:

$$K = mc$$

Note that, if the heat lost by the hot object is entirely given to the cold object as our model suggests:

$$\begin{pmatrix}\text{Heat lost}\\ \text{by Hot object}\end{pmatrix} = \begin{pmatrix}\text{Heat gained}\\ \text{by Cold object}\end{pmatrix}$$

$$m_{hot}c_{hot}\Delta T_{hot} = m_{cold}c_{cold}\Delta T_{cold}$$

Given that the temperature change **ΔT** is the difference of the beginning and ending temperatures and that both objects end up in thermal equilibrium with one another, the equilibrium temperature may be solved algebraically:

$$T_{EQ} = \frac{m_{hot}c_{hot}T_{hot} + m_{cold}c_{cold}T_{cold}}{m_{hot}c_{hot} + m_{cold}c_{cold}}$$

The total amount of heat necessary to change the phase of **m** grams of a material having a latent heat **L** is:

$$\Delta Q = mL$$

Group-work Examples:

#1 Determine the heat necessary to melt 15 g of ice.

#2 Find the equilibrium temperature of 54 g of ice at 0 ºC mixed with 106 g of water at 57 ºC.

#3 If 40 g of ice at 0 ºC is mixed with 5 g of steam at 100 ºC, what is the equilibrium temperature?

#4 Find the equilibrium temperature when 3 g of steam are allowed to interact with 75 g of aluminum at 10 ºC.

#5 What happens when 5 g of steam at 100 ºC interacts with 300 g of ice at 0 ºC?

Figure C.70. HBL HT Lecture 3 - page 2

C.7 Electric Circuits

All Electric Circuits HBL material created for Physics 1313 is presented in this section.

C.7.1 HBL Laboratories

All 7 HBL Electric Circuits Laboratories appear in the following Figures.

Physics 1313
Experiment EC 1 Outline

EC 1 - Batteries, Bulbs, and Wires			
Background	The goal of this module is to create a working model that allows successful prediction of the relative brightness of bulbs and other physical parameters in an electrical situation. We begin our investigations with an investigation of elementary electrical devices. We will be using three elements in this lab. **Batteries** are sources of electricity. **Wires** are devices used to connect electrical elements. **Bulbs** utilize electricity to cause light. Each of these elements will be used in a variety of ways throughout this module.		
Equipment	"D" - cell batteries	bulbs	white plastic covered wires, 6" - 9" long
Experimental Setup	Each pair of students at each station will receive one battery, one bulb, and one wire. No additional equipment is available for this lab.		
Initiating Event	Students are given the equipment and asked to explore.		
Required Submissions	Students work in pairs, collaborating on an experiment for each student. At least twenty observations from each student are required. An original, completed HBL worksheet is required from each student.		
That's odd...	It seems that there may be more than one way to light the bulb. Not all arrangements of a single wire, single battery, and single bulb cause the bulb to light. Lighting the bulb with this equipment wasn't as easy as it first seemed.		
Food for Thought	Don't we need additional equipment to cause the bulb to light? What is the purpose of the white stuff on the wires? Can you determine how this situation "works"? What are the requirements for a bulb to light?		

Figure C.71. HBL Laboratory EC 1 - page 1

Physics 1313
Experiment EC 2 Outline

EC 2 - Electrical Properties			
Background	As the last lab indicates, not every arrangement of a single bulb, single battery, and single wire will allow the bulb to light. The four different arrangements that *do* allow the bulb to light have one thing in common: if you trace the arrangement of the elements, a circular pattern emerges. This circular path that allows the bulb to light we call a **circuit**. Not every circuit allows the bulb to light. Not every type of material behaves the same way when exposed to electricity. We can separate materials into two distinct categories based on the behavior of a light bulb when they are placed into a circuit. In general, we call materials that allow the bulb to light **conductors**, and those materials that do not allow the bulb to light **insulators**. Obviously, some materials may allow the bulb to light under certain conditions, but not light under other conditions. We call this category of materials **semiconductors**, and they play an important part in our interactions with the technological devices of our everyday world. In fact, most of the electronic and electrical devices in use today depend on semiconducting materials.		
Equipment	"D" - cell batteries	bulbs	white plastic covered wires, 6" - 9" long
	electrical materials kit - includes many different types of materials		
Experimental Setup	Each pair of students at each station will receive one battery, one bulb, one electrical materials kit, and two wires. No additional equipment is available for this lab.		
Initiating Event	Create a circuit that allows a single bulb to light with help from the students. Indicate the intention to place a nail into the circuit, and solicit predictions. Insert the nail into the circuit and ask for observations. Repeat this procedure for a plastic poker chip.		
Required Submissions	Students work in pairs, collaborating on an experiment for each student. At least twenty observations from each student are required. An original, completed HBL worksheet is required from each student.		
That's odd...	Graphite seems strange.... Not all arrangements of a single wire, single battery, and single bulb cause the bulb to light.		
Food for Thought	Are all types of a particular material equally effective in allowing the bulb to light? What is the purpose of the white stuff on the wires? Can you find any materials that do not fit any one of the three categories above? Does it matter where the material is placed in the circuit?		

Figure C.72. HBL Laboratory EC 2 - page 1

Physics 1313
Experiment EC 3 Outline

<table>
<tr><th colspan="4">EC 3 - Electric Current</th></tr>
<tr><td>Background</td><td colspan="3">In general, we define a collection of elements and a battery that are connected electrically as a circuit. This implies that at least one conducting path exists from one end of the battery to the other. In the following lecture, we will investigate terminology and usage of specialized diagrams that allow us to describe circuits, but for now we will develop our experience with circuits and their elements further.

When a complete circuit is formed that includes a battery, we assume that some electricity flows from the battery to the elements of the circuit. This flow, or current, travels to the elements in a circuit and causes them to operate. In the case of a bulb, the presence of current causes the bulb to light. Given that current lights the bulbs, you may suspect that the brighter the bulb gets, the more current is present in the bulb. In fact, this is one of the fundamental assumptions that we make regarding circuits and bulbs. A common way to get an indication of the current present in a circuit is through the use of an indicator bulb. An indicator bulb is a single bulb connected directly to a single battery and that has a characteristic brightness. The value of an indicator bulb is that its brightness may be compared to other bulbs and the current through them relative to the indicator bulb deduced.</td></tr>
<tr><td rowspan="2">Equipment</td><td>"D" - cell batteries</td><td>bulbs</td><td>wires with alligator clips</td></tr>
<tr><td>battery holders</td><td>bulb holders (sockets)</td><td>Nichrome wire (or other wire of small diameter)</td></tr>
<tr><td>Experimental Setup</td><td colspan="3">Each pair of students at each station will receive two batteries and holders, four bulbs and sockets, one short length of Nichrome wire, and multiple alligator clip wires. No additional equipment is available for this lab.</td></tr>
<tr><td>Initiating Event</td><td colspan="3">Demonstration Activity
Obtain a single battery and one short length of Nichrome wire. Investigate the temperature of the wire along its length. Solicit predictions regarding any changes if the wire is connected to the ends of the battery.

Initiating Event
Arrange a single battery in a holder, single bulb in a socket, and wires such that the bulb lights. Name this the indicator bulb. Solicit observations regarding this situation.

Create two additional circuits, each composed of a single battery and holder, two bulbs in sockets, and wires. Note carefully that there are two different ways this may be done, and provide one of each type. Solicit predictions and observations regarding the circuits prior to lighting the bulbs and after they are lit.</td></tr>
<tr><td>Required Submissions</td><td colspan="3">Students work in pairs, collaborating on an experiment for each student. At least twenty observations from each student are required. An original, completed HBL worksheet is required from each student.</td></tr>
</table>

Figure C.73. HBL Laboratory EC 3 - page 1

That's odd...	A light bulb is always the same brightness, right? Some bulbs are brighter than others when connected to a single battery. Fingers are not good temperature sensors.
Food for Thought	Does current get "used up" as it flows? Is current flow one-way or round trip? Do we have any evidence which end of the battery has current flowing out of it? Does it matter where the bulbs are placed in the circuit?

Figure C.74. HBL Laboratory EC 3 - page 2

Physics 1313
Experiment EC 4 Outline

EC 4 - Series and Parallel Connections			
Background	Bulbs may be connected to one another in one of three distinct ways. If the bulbs are connected such that the conducting path goes through the first and then proceeds immediately through the next, the bulbs are said to be connected in **series**. A hallmark of series connections is that there are no other possible conducting paths between the bulbs - only a single conducting path exists between them. If the bulbs are connected by conducting paths in such a way that both ends of one bulbs are connected to both ends of a second bulb, they are said to be in **parallel**. Other paths may exist, but the important criterion for parallel connections is that each end of one bulb has a conducting path to each corresponding end of a second bulb. It is important to note that there may not be another element in the circuit along the conducting paths that lie between the elements in parallel. Finally, bulbs may be connected neither in series nor parallel. This type of connection is difficult to analyze without more advanced methods and models, but one should be aware of the existence of this type of connection. Recognizing how the bulbs are connected is an important step in extending our model to explain the behavior of electric circuits. It may happen that many individual bulbs can be connected in series or parallel with one another. We judge the connections between multiple bulbs in the same manner as with two bulbs. The battery in a circuit is a source of electrical current, as the bulbs will not light without a battery. However, the number and connections among bulbs can cause some to glow brightly and others to be not-so-bright. How might we understand this? One way of thinking about this behavior is to imagine that bulbs present some difficulty to the current generated by the battery. We model the difficulty presented to current flow as **electrical resistance**, or simply **resistance**. It is clear that the resistance of a given element or circuit may vary depending on the number and arrangement of the elements composing the circuit. This almost sounds analogous to the way water behaves as it travels through a pipe - if the water encounters a restriction in the pipe, less water flows; if the pipe does not interact with the water much, the flow can be quite large. In fact, this analogy between the behavior of water and electrical current is quite useful in a variety of ways. For instance, engineers trying to design a complicated array of pipes and fittings can treat their problem as a large electrical circuit to ease determination of the flow. We may expand upon this **water analogy** in the future to aid our understanding of electrical circuits, as we are all familiar with the function and behavior of water traveling through a hose.		
Equipment	"D" - cell batteries	bulbs	wires with alligator clips
	battery holders	bulb holders (sockets or socket boards)	
Experimental Setup	Each pair of students at each station will receive two batteries and holders, five bulbs and sockets (or a socket board), and multiple alligator clip wires. No additional equipment is available for this		

Figure C.75. HBL Laboratory EC 4 - page 1

	lab.
Initiating Event	Arrange a single battery in a holder, single bulb in a socket, and wires such that the bulb lights. Name this the indicator bulb. Solicit observations regarding this situation. Create two additional circuits, each composed of a single battery and holder, two bulbs in sockets, and wires. Note carefully that there are two different ways this may be done, and provide one of each type. Solicit predictions and observations regarding the circuits prior to lighting the bulbs and after they are lit. Solicit explanations of the behavior of the bulbs based upon the way the bulbs are connected and the idea of electrical resistance. Create a single battery circuit that lights two bulbs in series. Indicate the intention to place a third bulb in parallel with the second bulb, and solicit predictions and explanations regarding the circuits prior to lighting the bulbs. Light the bulbs and solicit explanations of the behavior of the bulbs based upon the way the bulbs are connected and the idea of electrical resistance.
Required Submissions	Students work in pairs, collaborating on an experiment for each student. At least twenty observations from each student are required. An original, completed HBL worksheet is required from each student. Additionally, three complete circuit diagrams with indications of relative brightness and an explanation of each bulb's behavior are required.
That's odd...	How can a complete circuit's conducting path go through a bulb that does not light? Some bulbs are brighter than others when connected to a single battery. The battery seems to "get tired" quickly in some situations.
Food for Thought	Does current get "used up" as it flows? How does the resistance of a collection of bulbs in series compare to the resistance of a single bulb? What does this do to the current through the combination? How does the resistance of a collection of bulbs in parallel compare to the resistance of a single bulb? What does this do to the current through the combination? Is there a general rule for determining the current exiting the battery compared to an indicator bulb circuit?

Figure C.76. HBL Laboratory EC 4 - page 2

Physics 1313
Experiment EC 5 Outline

EC 5 - Resistance	
Background	An analogy with water was introduced in the previous lab. In it, we saw that the behavior of water flowing through a pipe is similar to the flow of electric current. Using a bit of "common sense", we will explore some of the similarities between the two phenomena. Recall that **resistance** is conceptualized as the difficulty presented to current flow. In a water circuit, this idea of resistance is easily seen. Have you ever tried to drink through a straw? What about trying to drink through one of those small, short straws used as coffee stirrers? In the situation where one tries to drink through a normal straw, it is relatively easy for fluid to be moved, while it is exceptionally difficult for fluid to be moved through the smaller straw. This difficulty in moving the fluid is analogous to electrical resistance. In electrical circuits, we think of the flow of electricity as current, which is analogous to the *amount* of fluid flow through the straw in a water circuit. We understand that there are two fundamentally different ways of connecting bulbs (series and parallel) - can this model give some indication of the resistance of a combination of bulbs? Consider a series connection of a battery and two bulbs: the current flow proceeds along a single conducting path from the battery to the first bulb, directly to the second bulb, and returns to the battery. If the current has a single path to follow, an analogous water circuit would have one straw placed directly 'behind' the first. Common sense tells us that this would most likely be more difficult than drinking from a single straw (this seems similar to those "crazy straws" of past years). If our analogy holds, we would predict that a series circuit of two bulbs would have *more* resistance than a single bulb. Note that the amount of flow is small, indicating that the current in an electric circuit would also be small. Parallel circuits may be analyzed in the same fashion. Consider a parallel arrangement of a battery and two bulbs. Each bulb is connected to the battery by its own conducting path. An analogous water circuit would have two straws placed side by side - each has a direct connection from the fluid to the drinker's mouth. Common sense (and experience) tells us that it is quite easy to get a large amount of fluid to move through this combination. Thus, if the analogy holds, a parallel arrangement of a battery and two bulbs would have *less* resistance than a single bulb. Note that the amount of flow is large, indicating that the current in an electric circuit would also be large. A word of caution: note that the above analogies were carefully constructed. Each of the analogous portions had to be set up in the same way: in this case, the conducting paths for both circuits had to coincide. Additional analogies between water and electrical circuits exist and may be used freely, but the same care must be taken when creating them. Furthermore, there may exist additional correspondences between the situations. For instance, what is analogous to the battery? Does that element have one (or more) properties of the battery? If the resistance of a combination of electrical elements is known, the current flow among them may be deduced. As seen in the lecture, in the last lab, and the above analogy, when the resistance of a circuit is high, the current flow through the circuit is low. If the resistance is low, the current flow is high.

Figure C.77. HBL Laboratory EC 5 - page 1

	One point of interest here may involve the mathematics of **inverse proportionalities**. Generally speaking, when one quantity increases and another (related) quantity decreases, we say they are **inversely related** to one another. Mathematically this is the situation when the product of the two variable values equals a constant. For instance, if **A*B** = 1, this may happen if **A** is 2 and **B** is 0.5, when **A** is 10 and **B** is 0.1, or when **A** is 0.25 and **B** is 4. Note that in every one of these situations, one value was large while the other was small. Also notice that, in this case, the value of one variable may be obtained by taking the **reciprocal** of the variable that is known (dividing one by the value of the known variable). It is possible to connect bulbs in many ways. Sometimes we need to think about what would happen if some bulbs were connected in a certain way and then this **combination** was treated as a unit that could be connected to other bulbs in series or parallel. In fact, this happens in a wide variety of situations. Using the water analogy, we note that when the kitchen sink is turned on at home, it is also possible to get water from *any* other water fixture in the house. The act of turning on a fixture does not keep water from going anywhere else. How are these elements connected? One of the most commonly held pieces of wisdom regarding the behavior of electricity is: "Electricity takes the path of least resistance." From lab experiences and the above analogy, it is seen that it is certainly true that when the resistance is low, *more* electricity flows than would if the resistance were high. Therefore, you are encouraged to think of this common saying as a general guideline rather than the absolute truth. For instance, what would this saying indicate about a circuit composed of one battery and three bulbs if a combination of two bulbs in series were placed in parallel with a single bulb?		
Equipment	"D" - cell batteries	bulbs	wires with alligator clips
	battery holders	bulb holders (sockets or socket boards)	
Experimental Setup	Each pair of students at each station will receive two batteries and holders, five bulbs and sockets (or a socket board), and multiple alligator clip wires. No additional equipment is available for this lab.		
Initiating Event	Arrange a single battery in a holder, single bulb in a socket, and wires such that the bulb lights. Name this the indicator bulb. Solicit observations regarding this situation, particularly regarding the resistance and current at various points in the circuit. Create two additional circuits, one series and one parallel, each composed of a single battery and holder, two bulbs in sockets, and wires. Solicit predictions and observations regarding the circuits, particularly regarding the resistance and current at various points in the circuit, both prior to lighting the bulbs and after they are lit. Solicit explanations of the behavior of the bulbs based upon the way the bulbs are connected and the idea of electrical resistance. Create a single battery circuit that has a battery and three bulbs: one bulb in series with the parallel combination of the second and third bulbs. Solicit predictions and observations regarding the circuit, particularly regarding the resistance and current at various points in the circuit, both prior to lighting the bulbs and after they are lit. Solicit explanations of the behavior of the bulbs based upon the way the bulbs are connected and the idea of electrical resistance.		

Figure C.78. HBL Laboratory EC 5 - page 2

Physics 1313
Experiment EC 6 Outline

EC 6 - Resistance and Current Relationships	
Background	Using our lab experiences and the water analogy, we consider several different situations to get a general model relating current and electrical resistance for multiple bulbs. We need some numerical way of thinking about current and resistance, so we will conceptualize that they can be measured in "units". Units may be something we explore further in another context. As usual, all our conclusions will be relative to a single bulb circuit, where we consider the bulb to have one unit of resistance and one unit of current. Bulbs may be connected in three distinct ways: series, parallel, or neither series nor parallel. For convenience, a group of bulbs that are all connected in the same manner are called a **combination** or a **network**. Note that, in some circumstances, combinations of bulbs may themselves be connected to form larger combinations. In this case, analysis of the circuit's resistance should proceed from the innermost network outwards to encompass the entire circuit. Each network or combination can be treated as a single bulb having the total resistance of the combination in the analysis. Consider a circuit with two bulbs in series. The water analogy indicates that it is *twice* as difficult for flow to pass through two obstructions rather than one, indicating that the actual flow through both would be reduced to *half* the flow through a single obstruction. Thus, the resistance of this combination is two units while the current through the combination is one-half of a unit. Parallel arrangements of bulbs exhibit a different behavior. Our water analogy indicates that the total flow through two side-by-side identical obstructions is *twice* the flow through a single obstruction, supporting the conclusion that the overall resistance to flow was *half* as much as a single obstruction. Thus, the resistance of this combination is one-half of one unit, while the current from the combination is two units. Further extension of this model is possible. The following formulae give a formal way of calculating the resistance for bulb combinations that are either in series or in parallel. The pattern of either formula is continued until all the bulbs that are connected the same way are done. In general, the resistance of a combination of bulbs is referred to as the **equivalent resistance** of that combination. The idea here is that the combination could be replaced by a single bulb having this calculated resistance. $\text{Series}: \quad R_S = R_1 + R_2 + \cdots + R_N$ $\text{Parallel}: \quad \frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots + \frac{1}{R_N}$ Continuing the above analogy, when the resistance of a circuit is high, the current flow through the circuit is low. If the resistance is low, the current flow is high. This is a clear indication of an inverse proportionality. Thus, the current through a combination of bulbs is given by: $I = \frac{1}{R_{Combination}}$

Figure C.79. HBL Laboratory EC 6 - page 1

Equipment	"D" - cell batteries	bulbs	wires with alligator clips
	battery holders	bulb holders (sockets or socket boards)	
Experimental Setup	Each pair of students at each station will receive two batteries and holders, five bulbs and sockets (or a socket board), and multiple alligator clip wires. No additional equipment is available for this lab.		
Initiating Event	Students are to draw the following circuit on the board. This circuit contains a single battery and three bulbs. Two of the bulbs are connected in series, with the third bulb in parallel with the series combination. The large combination of all three bulbs is then connected to the battery. Solicit predictions based upon the above model regarding the resistance and current at various points in the circuit. All predictions should be made relative to an indicator bulb. Create the circuit and test the predictions.		
Required Submissions	Students work in pairs, collaborating on an experiment for each student. At least twenty observations from each student are required. An original, completed HBL worksheet is required from each student. Additionally, two complete circuit diagrams with indications of relative brightness and an explanation of each bulb's behavior are required. Each circuit must have a minimum of four bulbs.		
That's odd...	Adding bulbs can *decrease* resistance! Being certain of the way bulbs are connected is crucial. The reciprocal portion of the parallel mathematics is easy to forget.		
Food for Thought	How are the total resistance of the circuit and total current from the battery related? How can the amount of current passing down a particular branch of a circuit be predicted?		

Figure C.80. HBL Laboratory EC 6 - page 2

Physics 1313
Experiment EC 7 Outline

<table>
<tr><th colspan="4">EC 7 - Voltage</th></tr>
<tr><td>Background</td><td colspan="3">Continuing our water analogy, we investigate another feature that may have an analogue in an electrical circuit. For water to flow through a pipe, it must be pushed - the 'harder' the water is pushed, the more water flows through the pipe. This 'push' is not simply a force that is exerted on the water, but rather a force that is "spread out" over the entire cross-sectional area of the water in the pipe. This distribution of force over an area is called pressure. The pressure experienced by the water determines the flow rate of the water - when the pressure is high, the flow rate is high; low pressures cause low flow rates.

For a water circuit, if we examine the flow amount and resistance to flow we find an interesting feature at any constant pressure: when the flow rate is low the resistance to flow is high, while high flow rates correlate with low resistance to flow. This sounds rather like our electrical circuit model! Using what we know about inverse proportionalities, we see that the flow rate and resistance to flow are inversely related and their product is some constant value. The question is, what does the constant represent? To understand the constant, we speculate what happens when the pressure is changed. If the resistance to flow through a given pipe depends only on the physical features of the pipe and the physical properties of the fluid, increasing the pressure will increase the flow, while decreasing the pressure reduces the flow amount. This shows that the product of the flow amount and resistance to flow changes in the same way as the applied pressure! Thus, we postulate that the product of the flow rate and resistance to flow is the pressure:
(Applied Pressure) = (Flow Amount)* (Resistance to Flow)

We have already established that electrical circuits exhibit the same behavior: the product of the current and resistance is a constant. The logical question is: "What is the constant, and what does it represent?" Whatever the constant is, the results of the water circuit analogy indicate that it represents the ability of a circuit element to cause current to flow - in effect, 'pushing' current around the circuit. What electrical circuit element causes current to flow? Obviously, the presence of the battery in a circuit is necessary for current. Additionally, more batteries connected to an identical circuit sometimes cause greater currents. Thus, some property of the battery must be causing the current flow. We call this property voltage.

We know that bulbs may be connected in three distinct ways: series, parallel, or neither series nor parallel. Two general rules emerge for networks of bulbs:
• Series networks of bulbs all receive the same current.
• Parallel networks of bulbs all have the same voltage applied across them.</td></tr>
<tr><td rowspan="2">Equipment</td><td>"D" - cell batteries</td><td>bulbs</td><td>wires with alligator clips</td></tr>
<tr><td>battery holders</td><td>bulb holders (sockets or socket boards)</td><td></td></tr>
<tr><td>Experimental Setup</td><td colspan="3">Each pair of students at each station will receive three batteries and holders, five bulbs and sockets (or a socket board), and multiple alligator clip wires. No additional equipment is available for this</td></tr>
</table>

Figure C.81. HBL Laboratory EC 7 - page 1

	lab.
Initiating Event	Students are to draw the following circuit on the board. This circuit contains a single battery and three bulbs. A parallel network of two bulbs is connected in series with the third bulb. This series network is then connected to one battery. Solicit predictions based upon the above model regarding the resistance and current at various points in the circuit. All predictions should be made relative to an indicator bulb. Create the circuit and test the predictions. Students are to modify their circuit by adding a second battery. Solicit predictions based upon the above model regarding the resistance and current at various points in the circuit. All predictions should be made relative to an indicator bulb. Create the circuit and test the predictions.
Required Submissions	Students work in pairs, collaborating on an experiment for each student. At least twenty observations from each student are required. An original, completed HBL worksheet is required from each student. Additionally, two complete circuit diagrams with indications of relative brightness and an explanation of each bulb's behavior are required. Each circuit must have a minimum of four bulbs.
That's odd...	*Batteries* can be connected in networks! This model allows prediction of how currents divide within parallel networks! For a given circuit, many batteries *do not* always provide more current than a single battery.
Food for Thought	How are the total resistance of the circuit, the number of batteries, and total current related? What is the relationship between the way batteries are connected and the current they output to the circuit? What is the significance of the "+" and "-" symbols on the battery?

Figure C.82. HBL Laboratory EC 7 - page 2

C.7.2 HBL Class Activities

The 2 HBL Electric Circuits class activities appear in the following Figures.

HBL EC Summary 1

A bare wire touched to both terminals of a battery gets hot along its entire length. We attribute this to the flow of electricity, called electrical current (or just **current**). The usual algebraic symbol for current is **I**. Since the wire got uniformly hot along the wire, the current in the wire must have been the same throughout the wire.

We have seen that only certain arrangements of wires, batteries and bulbs allowed the bulbs to light up. In any of the arrangements that actually lit the bulb, the elements formed some kind of closed, roughly circular arrangement. We call any combination of wires, batteries and bulbs that actually light the bulb a **complete circuit**, closed circuit, or just **circuit**. Current may flow even if it does not light a bulb – the only requirement for current flow is a complete circuit.

Inserting different materials into a circuit sometimes allowed the bulb to light up, and sometimes not. Generally speaking, those kinds of materials that allowed the bulbs to light up when inserted into the circuit were metals (but not always, as in the case of graphite). These materials we call **conductors**, since they allow electricity to travel through them with ease. Almost any nonmetallic substance (with the exception of mechanical pencil lead, or graphite) did not allow the bulb to light up. These materials we call **insulators**, since they do not allow electricity to flow through them easily. Other materials, such as silicon and germanium, are called **semiconductors** and allow the bulb to light in some circumstances but not in others.

As a general rule for the remainder of EC, **we will assume that the brightness of a bulb indicates the amount of current through that bulb**: when the bulb is bright, the current is large, when dim, the current is small. When comparing the brightness of bulbs, you should be aware that most bulbs will be made the same way, but may have small imperfections from the manufacturing process. These differences may cause the bulbs to be slightly different in brightness even when they receive the same current. These brightness differences are small, thus we typically must judge at what point the brightness change is significant.

Circuit Diagrams:
A circuit diagram is a schematic representation of the elements contained within the circuit. It uses special symbols for each element:

Battery　　Bulb　　Wire　　Switch

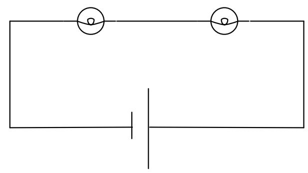
Wires that are electrically connected are drawn differently than wires that are not in electrical contact:

In contact (junction)　　No contact

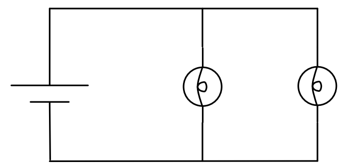
Circuit diagrams do not simply show the physical layout of the elements in the circuit, but rather illustrate the electrical connections among the elements.

Figure C.83. HBL EC Lecture 1 - page 1

There are two distinct ways two bulbs can be connected. If one bulb is connected directly behind the other, the two bulbs are said to be in **series.** If both bulbs are connected in such a way that each of their ends is connected to each of the other bulb's ends, they are said to be in **parallel**. Both are represented below:



Series



Parallel

Combining additional elements in series or parallel with one another may make more complicated circuits. It is worth noting, however, that not all connections are either series or parallel – it may turn out that it is neither.

You have seen that the brightness of these arrangements of bulbs is not always the same. We understand this by noting that each bulb presents some impediment, or **resistance**, to the current. The algebraic symbol for resistance is **R**. There may be some relationship between the resistance and current flow in the circuit.

Follow-up Questions:

Does current get used up as it flows around the circuit?

Determine the insulating and conducting components of a bulb, a switch, a battery holder, and a light socket. Draw a diagram of each, labeling each component for each element.

How does the brightness of bulbs connected in series compare with a single bulb circuit?
How does the current in a series circuit compare with a single bulb circuit?
How does the resistance in a series circuit compare with a single bulb circuit?

How does the brightness of bulbs connected in parallel compare with a single bulb circuit?
How does the current in a parallel circuit compare with a single bulb circuit?
How does the resistance in a parallel circuit compare with a single bulb circuit?

Is the current coming out of the battery always the same?

What is the relationship between the resistance of the circuit and the current flow in the circuit?

Figure C.84. HBL EC Lecture 1 - page 2

HBL EC Lecture 2

Recall from previous experiments:

- Current does not get "used up" as it flows.
- The only method we know for dividing or sharing current requires multiple conducting paths.
- Any combination of wires, batteries and bulbs that actually lights the bulb is a complete circuit.
- We assume that the brightness of a bulb indicates the amount of current through that bulb.
- We have seen that a bulb's brightness is not always, directly proportional to its current.
- Bulbs may be connected in three different ways: series, parallel, or neither series nor parallel.
- The difficulty bulbs present to current flow is resistance.
- Several bulbs connected in the same manner are a network.
- The resistance of a single series or parallel network can be calculated according to:

$$\text{Series:}\quad R_{Series} = R_1 + R_2 + \cdots + R_N$$

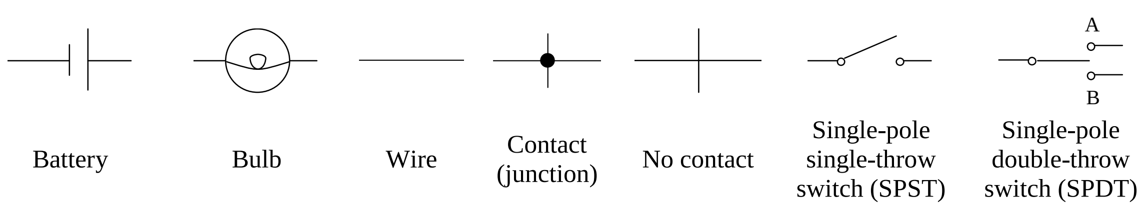
$$\text{Parallel:}\quad \frac{1}{R_{Parallel}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots + \frac{1}{R_N}$$

- Networks of bulbs may be treated as single bulbs having the electrical properties of the network.
- We may make networks of networks and use the above mathematics to calculate their total resistance.
- The product of total current and total resistance is a constant called voltage.
- We conceptualize resistance, current, and voltage to be measured in "units".
- The current output from the battery to the circuit is not constant, and (for a single battery) is given by:

$$\mathrm{I} = \frac{1}{\mathrm{R}_{total}}$$

- Batteries may be connected in series or parallel and behave differently.
- Series networks receive the same current.
- Parallel networks receive the same voltage.
- The voltage across a network may be calculated according to Ohm's Law below.
- Circuits may be drawn using circuit diagrams that illustrate electrical, not physical, connection.

Circuit diagrams are schematic representations of the elements contained within a circuit using special symbols for each element. **Circuit diagrams do not simply show the physical layout of the elements in the circuit, but rather illustrate the electrical connections between the elements.**



Note: The SPDT switch has two different conducting positions and is **always** connected to one of them. The SPST switch is either open or closed.

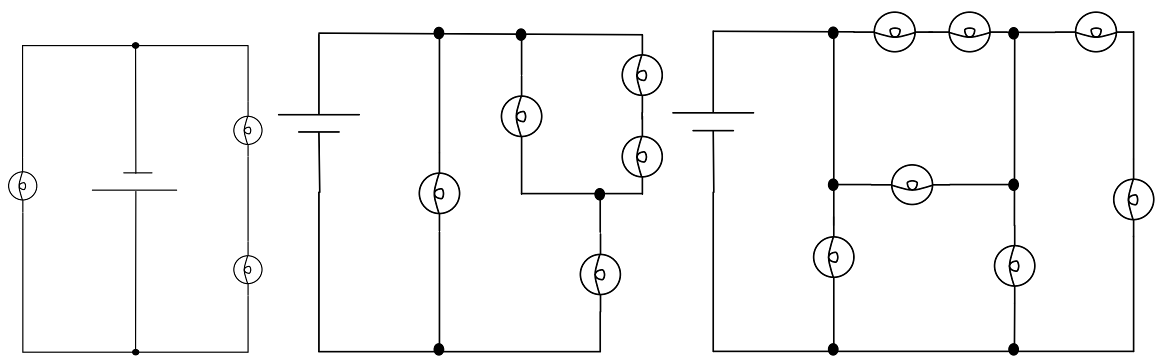
The relationship between voltage, current, and resistance is called **Ohm's Law**. Formally, Ohm's Law is:

$$V = I \cdot R$$

We can use the units developed in class for resistance and current, and should use the voltage in units of batteries applied to the circuit (that way, the results are consistent with an indicator bulb). When networks are present, the voltage across the network may be calculated as the product of the current through the network times the network's resistance. This may be used to determine how current divides within parallel networks.

Figure C.85. HBL EC Lecture 2 - page 1

Follow-up Questions:
Calculate the total resistance, total current and relative brightness of every bulb in the following circuits. Assume the bulbs will light and that all bulbs are identical.



Can an individual bulb be connected in series and parallel at the same time?

Figure C.86. HBL EC Lecture 2 - page 2

VITA

Charles Edward Hasty

Candidate for the Degree of

Doctor of Philosophy

Thesis: ASSESSING THE EFFECTIVENESS OF THE HBL PEDAGOGY

Major Field: Physics

Biographical:

Personal Data: Born in Ponca City, Oklahoma, on January 28, 1968, the son of Margaret and Wallace Hasty.

Education: Graduated from Malone High School, Malone, Florida in May 1986; received Bachelor of Science degree in Physics with an Engineering option from Oklahoma State University, Stillwater, Oklahoma in December 1990. Received Master of Science degree in Physics from Oklahoma State University, Stillwater, Oklahoma in December 1993. Completed the requirements for the Doctor of Philosophy degree with a major in Physics at Oklahoma State University in December 2005.

Professional Memberships: Phi Kappa Phi.

Name: Charles Edward Hasty | Date of Degree: December, 2005

Institution: Oklahoma State University | Location: Stillwater, Oklahoma

Title of Study: Assessing the Effectiveness of the HBL Pedagogy

Pages in Study: 240 | Candidate for the Degree of Doctor of Philosophy

Major Field: Physics

Scope and Method of Study: An exploratory set of studies was conducted to compare the effectiveness of the HBL and PBI pedagogies. During two different semesters (fall 2003 and spring 2004), 83 Oklahoma State University elementary education students (77 female, 6 male) received identical content instruction differing only in pedagogy. Students were assessed regarding self-efficacy, physics expectations, science process skills, and physics content.

Findings and Conclusions: Analyses reveal that HBL and PBI cause statistically similar gains in elementary education students' self-efficacy scores and physics expectations. Both populations were similar before and after instruction, with similar changes in performance occurring on the same items; no statistically significant differences were caused by pedagogy. While no significant differences in Exam Item performance existed for Light and Color or Astronomy by Sight problems, HBL caused a significant student score improvement on the Electric Circuits problem. Analysis revealed that the SPAMSS instrument is likely inappropriate for this audience, although both groups scored approximately 90% on the instrument. The major analysis conclusion is that HBL produces largely the same results as PBI, providing explicit evidence that open and directed inquiry pedagogies can be equally effective.

ADVISOR'S APPROVAL Dr. Bruce J. Ackerson