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COMPARISON OF GUIDED AND OPEN INQUIRY INSTRUCTION IN A HIGH SCHOOL PHYSICS CLASSROOM

by

Brett M. Guisti

A thesis submitted to the faculty of

Brigham Young University

in partial fulfillment of the requirements for the degree of

Master of Science

School of Technology

Brigham Young University

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BRIGHAM YOUNG UNIVERSITY

GRADUATE COMMITTEE APPROVAL

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BRIGHAM YOUNG UNIVERSITY

As chair of the candidate's graduate committee, I have read the thesis of Brett M. Guisti in its final form and have found that (1) its format, citations, and bibliographical style are consistent and acceptable and fulfill university and department style requirements; (2) its illustrative materials including figures, tables, and charts are in place; and (3) the final manuscript is satisfactory to the graduate committee and is ready for submission to the university library.

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ABSTRACT

COMPARISON OF GUIDED AND OPEN INQUIRY INSTRUCTION IN A HIGH SCHOOL PHYSICS CLASSROOM

Brett M. Guisti

School of Technology

Master of Science

This study compared two levels of inquiry in high school physics classrooms over a year-long course. One class fit well the definition of guided-inquiry and the other matched common descriptions of open-inquiry. Four sections of introductory physics at Lone Peak High School in Highland, Utah were randomly divided into two sections for each treatment. The majority of students in all classes were sophomores with relatively few juniors and seniors. The guided-inquiry classes followed the Modeling Instruction Program developed at Arizona State University, while the open-inquiry classes were be based on an approach used by Wolff-Michael Roth, at the University of Victoria, British Colombia.

The independent variable in this study was the level of inquiry of the high school physics class. The dependent variables of interest were the students' short-term and long-

term understanding of introductory physics concepts as well as the student's attitudes towards physics. The Force Concept Inventory (FCI) and the Utah State Criterion Referenced Physics Test (CRT) were used to judge learning of physics concepts and the Colorado Learning Attitudes about Science Survey (CLASS) was used to analyze changes in views towards physics.

FCI results showed no statistically significant differences in short-term or long-term mean scores between the two treatments. Small practical significance was found in the greater short-term mean gain scores of the guided-inquiry class with an effect size of .34. The CRT showed the open-inquiry class to have a higher mean score that was slightly statistically significant (p-value of .049) and at a medium level of practical significance with an effect size of .43. A curious result arose when comparing the scores on each of the FCI posttests. The open-inquiry treatment had a higher increase in average gain score that was found to have statistical significance with a p-value of .010 as well as practical significance in the medium range with an effect size of .57.

Both treatments were found to have somewhat unfavorable effects on students' opinions towards physics. Additionally, the open-inquiry treatment had a more polarizing effect on the attitudes of students towards physics. Open-inquiry students responded particularly positively on questions addressing "Problem Solving." For the open-inquiry students, positive shifts were strongest in questions addressing "Real World Connections" and "Personal Interest."

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1 Introduction

This study was primarily motivated by a desire to improve the teaching in my classroom. Incorporating that desire with a thesis gave me extra motivation and support to approach teaching high school physics in way (open-inquiry) novel and largely foreign to me, as well as to formalize a study of the outcomes. While I wanted all of my students to succeed, I was also hoping that my new approach would achieve equal if not superior results while giving students a more autonomous experience. As this study constitutes action research, the researcher and the instructor were one in the same.

1.1 Competing Philosophies

While each educational movement has its particularities, one can generalize most reform efforts of the past several decades to a struggle between teacher-centered and student-centered approaches (Chall, 2000; Fielding et al., 1983; Kirschner et al., 2006; Mayer, 2004). This line of demarcation between educational philosophies is evident in myriad terminologies applied to educational methods. Kirschner et al. (2006) defined the rift in terms of the amount of structure or guidance present in the classroom:

> On one side of this argument are those advocating the hypothesis that people learn best in an unguided or minimally guided environment, generally defined as one in which learners, rather than being presented with essential information, must discover or construct essential information for themselves (e.g., Bruner, 1961; Papert, 1980; Steffe & Gale, 1995). On the other side are those suggesting that novice learners

> should be provided with direct instructional guidance on the concepts and procedures required by a particular discipline and should not be left to discover those procedures by themselves (e.g., Cronbach & Snow, 1977; Klahr & Nigam, 2004; Mayer, 2004; Shulman & Keisler, 1966; Sweller, 2003). (p. 75)

While there are undoubtedly pros and cons to each approach, it has been proposed that their superposition can lead to unintended circumstances. For example, Bencze (2000) comments that, "Many educators continue to face the dilemma of wanting students to become independent thinkers, while not being able to resist the urge to engineer their thinking…However, such stage-managed conceptual reconstructions in the context of investigative activities seriously compromise students' opportunities to gain literacy and independence" (p. 849-850). The underlying notion is that being true to an educational philosophy can help give a classroom a sense of purpose and direction.

Teacher-centered approaches are often referred to as traditional, didactic, or direct instruction. They stress transmission of knowledge in a manner that emphasizes training or memorization. Costenson & Lawson (1986) described this traditional method as "teaching centered around one fact-laden text…consist[ing] of assign, recite, test, and then, discuss the test" (p. 150). The term "teacher-centered" comes from the role that the teacher assumes in a traditional classroom: possessor of knowledge to be transferred to students and principal decision maker as to how that knowledge transfer is to take place.

Teaching styles that are often referred to as student-centered include discovery, constructivist, inquiry, experiential, and problem-based learning (Kirschner et al., 2006). These approaches are characterized by students sharing some degree of the responsibility for making decisions in the classroom. The teacher is often described as a partner or a facilitator in the learning process. It is argued that learning in a student-centered environment is more personally meaningful and durable as the student is a more active participant in the learning process (Walker, 2007, p. 10). Another common claim of student-centered teaching is that the learner ultimately decides what information he takes in and what sense he makes of it. Mayer (2004) described this idea in reference to constructivism, “an underlying premise is that learning is an active process in which learners are active sense makers who seek to build coherent and organized knowledge” (p. 14). Practices that support these student-centered approaches commonly include less-structured activities such as open-ended projects that focus on problem solving or analytical skills rather than mastering facts.

1.2 Current State of the Debate

After years of research conducted on each side of the philosophical debate, groups representing student-centered and teacher-centered philosophies have claimed evidence that their approach is the superior one (Ellis et al., 1994). A response to the common refrain that educators do not employ research-based teaching practices could well be, “Which ones?” This leaves today’s landscape of educational research as largely a mélange of recycled ideas, neatly packaged and stamped with new buzz words. Curiously, the language of student-centered teaching has become ubiquitous in educational circles whereas the practices of the teacher-center approach appear to be a mainstay in the classroom.

Professional, in-service, and collaborative meetings are rife with student-centered vernacular. Examples include a U.S Department of Education study of professional development that spoke often of “a higher-order teaching strategy” and “the use of problems with no obvious solution" (Porter et al., 2000, p. ES-5). The National Research Council suggested in their National Science Education Standards (1996) that, "engaging students in inquiry helps develop an understanding of scientific concepts, an appreciation of "how we know" what we know in science, an understanding of the nature of science, skills necessary to become independent inquirers about the natural world, and dispositions to use the skills, abilities, and attitudes associated with science" (p. 105).

While schools are not devoid of student-centered practices, traditional methods appear to remain the prevalent approach. One study of the instructional practices of community college instructors (Barrett et al., 2007) found 84% of the 292 participants used predominantly teacher-centered instructional methods. Dana (2001) noted that:

> During the 1980's and 1990's, classroom observations revealed plenty of examples of the absence of inquiry-based teaching or opportunities for higher level thinking (Maor, 1991). Teachers have retained a belief in learning through 'transmission' … Overall secondary science teaching has changed little in the last 40 years. Science in secondary schools is still largely fact driven and didactic. Current curricula consist of textbooks, teacher talk, and testing. (p. 7-8)

It appears that a dichotomy has arisen between educational talk and educational practice.

1.3 A Direction for Student-Centered Research

Since the teacher-centered approach has been, and continues to be the status quo (Barrett et al., 2007; Dana, 2001; Maor, 1991), it is probable that direct instruction will remain the dominant teaching method as long as a definitive body of research does not come down on the side of student-centered teaching. One obstacle faced by the student-centered advocates is how broadly terms such as inquiry and constructivism have been applied to widely differing classrooms. These classrooms might all share common theoretical underpinnings, but the practical applications ascribed to the same philosophical motive have outcomes as varying as their teaching methods (compare Kirschner et al., 2006, and Roth, 1994). The bifurcation all classrooms into teacher-centered or student-centered appears to be a generalization.

Rather than looking at student-centered versus teacher-centered classrooms in an all-inclusive manner as many researchers have done (Adams, 1997; Chomy, 1998; Fielding et al., 1983; Hake, 1998; Kirschner et al., 2006; Mayer, 2004), student-centered research can benefit from pinpointing the characteristics of inquiry that make it effective. To some extent the varying degrees of student-centeredness are recognized in the separation of inquiry into guided and open. Foos (2003) describes the common usage of these terms thus: "At the guided inquiry end of the spectrum, the instructor states the problem, formulates the hypothesis, and develops a working plan and the student performs the activity, gathers the data, and draws conclusions…[At the open inquiry end of the spectrum s]tudents state the problem, formulate the hypothesis, and develop their own working plan" (abstract). Though looking at inquiry as guided versus open is useful, this language is still too broad to describe accurately all types of student-centered classrooms.

In an effort to further clarify the spectrum of student-centered classrooms, Fradd et al. (2001) created a matrix (Table 1-1) to quantify the student-centeredness of a classroom. The matrix allows one to identify more concisely just how much responsibility is in the hands of the students.

Table 1-1: Science Inquiry Matrix

Inquiry Levels	Questioning	Planning	Implementing	Concluding		Reporting	Applying
			Carry out plan Record	Analyze data	Draw conclusion		
0	Teacher	Teacher	Teacher	Teacher	Teacher	Teacher	Teacher
1	Teacher	Teacher	Students/ Teacher	Teacher	Teacher	Students	Teacher
2	Teacher	Teacher	Students	Students / Teacher	Students/ Teacher	Students	Teacher
3	Teacher	Students / Teacher	Students	Students	Students	Students	Students
4	Students/ Teacher	Students	Students	Students	Students	Students	Students
5	Students	Students	Students	Students	Students	Students	Students

Though research comparing two different student-centered approaches has been scarce, there have been a few studies that have focused on de-globalizing the term inquiry. One study (Faulkner, 1992) looked at the differences in learning and attitudes of fifth and sixth graders resulting from one cellular biology activity conducted at varying levels of inquiry. A comparison was made between three levels of inquiry that were termed guided discovery, open inquiry, and discovery demonstration. Faulkner (1992) concluded, “that all hands-on treatments were equally efficacious in their effect on cell concept learning within both grade levels,” and that, “Attitudes toward science did not change within grade levels as a result of the treatments” (abstract). These findings indicate no significant differences in learning or attitudinal outcomes for different levels of student-centeredness.

In a similar study, Dana (2001) set out to observe the effects of the level of inquiry on student understanding in secondary physics classrooms. Unexpectedly, the teachers participating in the study all ended up using approaches on the guided-inquiry end of the spectrum. Dana (2001) reported that the study, "demonstrated limited effects of various levels of inquiry due to small sample size and lack of differentiation between teacher" (p. iv). Another researcher (Roth, 1994) was successful at studying open-inquiry in a high school physics setting by teaching the class himself. It was found to be a successful method by primarily qualitative measures, but no attempt was made to explicitly compare outcomes with those of any other approach.

1.4 Statement of the Problem

Disagreement persists among researchers over the efficacy of teacher-centered and student-centered teaching approaches. As traditional teaching methods are well ingrained in the education community, definitive evidence in favor of student-centered approaches is likely needed for a substantial change in classroom practices to be possible.

To help define student-centered approaches more clearly and to focus related research efforts, a few studies have looked at specific aspects of varying levels of inquiry. But these studies have yet to look at differing levels of inquiry applied over a year-long course. There has also been few, if any, studies comparing differing levels of inquiry specifically in a high school setting or in the discipline of physics.

To address these issues, this study compared two levels of inquiry in high school physics classrooms over a year-long course. The researcher was the instructor for both treatments. The level of inquiry in one classroom was rated by five science teachers to have an average score of 2.9 on the science inquiry matrix (Table 1-1) while the second class was rated at an average inquiry level of 4.4. The former class fit well the definition of guided-inquiry and the latter matched common descriptions of open-inquiry. The researcher compared scored responses on conceptual, computational, and attitudinal exams/surveys between guided and open-inquiry physics classrooms taught by the same instructor at the same high school to evaluate differences in student performance and attitudes.

1.5 Research Questions

1. Is there a statistically or practically significant difference in scored responses (short-term and long-term) for students experiencing a guided-inquiry teaching approach versus students experiencing an open-inquiry teaching approach in a high school physics classroom?
2. Is there a difference in survey responses regarding attitudes towards physics for students experiencing a guided-inquiry teaching approach versus students experiencing an open-inquiry teaching approach in a high school physics classroom?

2 Review of Literature

2.1 History of Student-Centered Teaching

Many of the principles of a student-centered approach to education have their roots in the philosophy of Rousseau. His work “Emile” particularly stresses the instinctual nature of children to investigate and naturally learn from experiences with their environment. The 19th century Swiss school teacher Johann Pestalozzi was heavily influenced by Rousseau’s writings and set up schools following similar principles. Pestalozzi believed in nurturing the student and placed particular importance on only introducing new terms once adequate familiarity with the concept was achieved through experience. The torch was picked up in the 20th century by the American educational philosopher John Dewey. His writings sparked the progressivist school movement of the 1940’s and 50’s. While Dewey shared the sentiment that education needed to start with the individual, he also accentuated the social nature of the educative process. While never gaining wide acceptance, progressive schools did become quite influential before going virtually extinct during the Cold War.

Today the most prevalent school of thought advocating student-centered ideas is a learning theory known as constructivism. While its application in the educational setting has obvious links to Dewey, its epistemological underpinnings are closely tied to the work of Jean Piaget where “what we call knowledge does not and cannot have the purpose of producing representations of an independent reality, but instead has an adaptive function" (von Glaserfeld, 2005, p. 3). The very existence of knowledge then is determined by the meaning that the learner is able to construct from his experiences, rather than one's familiarization with a static body of facts. Fosnot (2005) describes constructivism this way:

> Constructivism is a theory about knowledge and learning; it describes both what "knowing" is and how one "comes to know." Based on work in psychology, philosophy, science, and biology, the theory describes knowledge not as truths to be transmitted or discovered, but as emergent, developmental, nonobjective, viable constructed explanations by humans engaged in meaning-making in cultural and social communities of discourse. Learning from this perspective is viewed as a self-regulatory process of struggling with the conflict between existing personal models of the world and discrepant new insights, constructing new representations and models of reality as a human meaning-making venture with culturally developed tools and symbols, and further negotiating such meaning through cooperative social activity, discourse, and debate in communities of practice. (p. ix)

Dewey's emphasis on the social nature of learning is still present, yet where the progressive movement was in large part counter-establishment, rejecting all things traditional, constructivism accepts some level of authority and organization. Stemming more from a belief in the individual nature of the learning process rather than a Rousseauian rejection of societal impositions, constructivists do envision a classroom quite different from what is commonplace today. Fosnot (2005) continues:

> Although constructivism is not a theory of teaching, it suggests taking a radically different approach to instruction from that used in most schools…The traditional hierarchy of teacher as the autocratic knower, and learner as the unknowing, controlled subject studying and practicing what the teacher knows, begins to dissipate as teachers assume more of a facilitator's role and learners take on more ownership of the ideas. Indeed, autonomy, mutual reciprocity of social relations, and empowerment become the goals. (p. ix)

While similar sentiments are frequently expressed in educational settings, most classroom practices do not reflect this shift in objectives and methodology. Core curricula dictate the concepts covered and are employed to measure the success of a student.

A significant difficulty in discussing teaching approaches in today's classroom is the lack of common terminology in expressing related ideas. Terms such as student-centered, constructivism, inquiry, and discovery learning are often used interchangeably. "Various interpretations of constructivism still abound, often confusing it with 'hands-on' learning, discovery, and a host of pedagogical strategies" (Fosnot, 2005, p. x). While there are commonalities between these terms, experts in each field feel there are important differences.

2.2 Inquiry-Based Science

In the sciences, the term used most often to refer to student-centered approaches is "inquiry." The inquiry approach to teaching science has been advocated by the Physics Education Group lead by Lillian McDermott at the University of Washington. Their primary curricular publication is entitled "Physics by Inquiry" (McDermott et al. 1996). Their description of the work includes:

> *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. A major goal is to help students think of physics not as an established body of knowledge, but rather as an active process of inquiry in which they can participate. (McDermott et al., 1996)

Inquiry applies to a range of investigative activities with varying degrees of structure or teacher control. On the more structured end of the spectrum we have guided inquiry. This is not the cookbook lab where a teacher walks you through every step, instead "the instructor provides the problem and encourages students to work out the procedures to resolve it…The teacher asks questions giving students direction rather than telling them what to do" (Trowbridge et al., 2000, p. 209). The less structured end of the spectrum is referred to as free or open-inquiry. In this case the students would come up with their own research questions as well as methods of investigating their hypotheses. Many "discovery learning" activities might fall somewhere in between (Figure 2-1), where the research question and some equipment are supplied by the teacher, but the decisions about the exact methodology to be employed and the conclusions drawn are left up to the student. All of these methods are more student-centered than the traditional approach of direct instruction, but they vary in degree of student responsibility and autonomy. While hands-on and discovery activities have become part of nearly every science class, true constructivist classrooms remain quite rare.

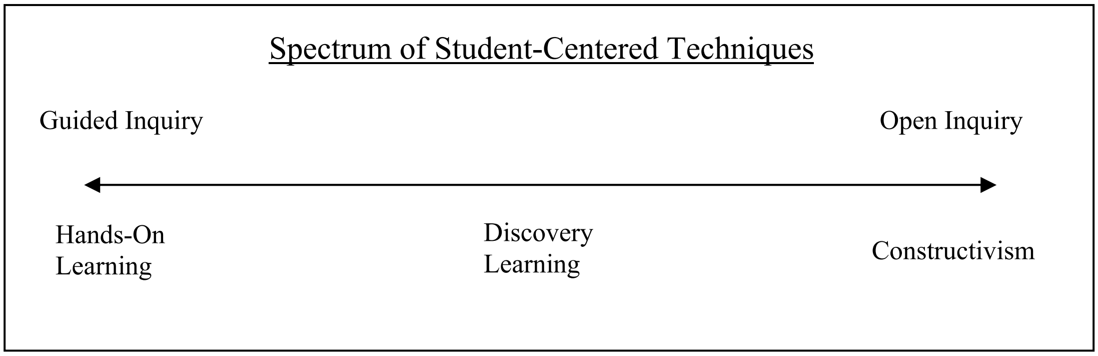

Figure 2-1: Student-Centered Spectrum

A constructivist approach in a physics classroom has been applied by Dewey I. Dykstra Jr., at Boise State University. Dykstra (2005) summarizes the evolution of his teaching philosophy in this way:

> I came to this constructivist point of view because of my belief that, as the result of teaching, one's students should have new understandings of the world. I found at the beginning of my career that when I taught as I had been taught, new understandings on the part of the students were not usually the result. Having looked for evidence of new understandings as a result of teaching at a wide range of levels over the past two decades, I have found that this is unfortunately the general state of affairs. I also do not believe that only certain smart people can *do* math and science. Holding these two beliefs has made life difficult…Left with the realization that typical physics instruction results in an unsatisfactory outcome and deprived of the typical ad hoc explanations for this failure, I wrestled in a great disequilibrium for a number of years. (p. 222-3)

An aspect of constructivism upon which Dykstra places particular importance is that of focusing on the student's preconceptions, specifically in getting the student to explicitly express what might otherwise remain tacit. It has been observed that students often learn a given subject matter well enough to use the correct terminology in discussing the topic and even perform well on examinations, yet later revert back to their previous ideas about the world. The new material seems to be disconnected from previous learning, rather than building on or replacing it. To combat this phenomenon, Dykstra decided to teach his introductory physics course quite differently from the traditional methods with which he had been taught.

Several days are spent carefully guiding the students to articulate and share their ideas with as little teacher influence as possible. As a given physical situation is demonstrated, students must explain what they are seeing, often in pictures and diagrams as well as prose. The class then shares their ideas, and when differences of opinion arise, students are encouraged to communicate their reasoning in an effort to come to a consensus. When there is agreement between a majority of students, they are then asked to apply their ideas to make predictions about another physical situation. It is a usual practice in a physics class to give demonstrations that challenge common misconceptions, but taking more time to have students think about and commit to their predictions helps the discrepant events to lead to actual conceptual change. Dykstra puts it this way, "My goal ultimately is to maximize the chances that the students will be disequilibrated. The more explicit and detailed their ideas are to themselves and the greater their commitment to these explanations, the more likely the disequilibration when the students decide for themselves that the explanations do not make sense" (p. 230). The greater the buy-in on the part of the student, the greater the chances of long term learning taking place.

Another example of a constructivist physics classroom focuses on the autonomy of the student in originating and testing research questions. Wolff-Michael Roth (1994), at Simon Fraser University, taught an experimental high school course at a private school in central Canada. "He used a graduate student advisor metaphor as referent for the planning of, and acting in, the learning environment" with "about six to seven of the nine periods in a two-week cycle" spent on experimentation (p. 201-2). The occasional class period not spent in the lab was used for class discussions or introducing new tools for collecting or analyzing data. Often the instructor would supply an initial research question when a new topic was to be covered, but then students would be responsible for subsequent investigations. The idea was for the students to "take individual responsibility for their learning" (p. 201) in a setting similar to a graduate student working with an advisor. The students worked in groups to generate their own research questions, experimental methodology, and to analyze their results. The instructor would then provide feedback on their lab reports that "included alternate interpretations, different graphical and statistical analysis procedures using the student data set as an example, suggestions for error sources, suggestions for everyday application, general encouragement, and praise" (p. 202). The focus was more on the process and interpretations rather than the replication of established science.

Many teachers experienced in traditional approaches to education would likely react to this course construction with concerns of managing and motivating students in such an unstructured environment. Roth (1994) reports:

> Our results are in marked contrast to earlier studies in science laboratories, which indicated that open inquiry was too confusing and did not work for most students, that learning outcomes were too uncertain, and that students were little concerned with meaningful learning but mostly pursued their own agendas of a social nature. We found a remarkable ability and willingness to generate research questions, to design and develop apparatus for data collection, to deal with problems arising during implementation out of the context of inquiry, and to pursue meaningful learning during the interpretation of data and graphs to arrive at reasonable answers of their focus questions (p. 204).

The students themselves noted the stark difference between the constructivist laboratory and the traditional approach used in many of their other science courses. "Most students did not like the cookbook approach of traditional laboratories because the purpose of most steps remained hidden from them. Thus, they completed a chemistry laboratory exercise without knowing why they took each step" (p. 211). The novelty of the open-inquiry experience did lead to an adjustment period of 3-4 months before the students were really comfortable with how to proceed (Roth, 2007).

Roth (1994) reported that students conducted science experiments in a manner much more closely resembling the work of actual scientists and "used reasoning modes similar to those that appear during everyday practices of scientists and nonscientists alike" (p. 216). As the students formulated and researched their own questions, the sentiment towards the lab experience shifted from a task to be completed to a personal inquiry for which an answer was sought.

3 Methodology

3.1 Purpose

The purpose of this study was to compare the outcomes of a guided-inquiry with an open-inquiry teaching approach in a high school physics classroom. The outcomes that were investigated were academic student performance and student attitudes towards physics.

3.2 Classroom Contexts

The classes involved in this study were taught at Lone Peak High School in Highland, Utah during the 2007-2008 school year. Lone Peak had 1,974 students (52% male, 48% female) in 2006 and is part of the Alpine School District which had 52,920 students and 67 schools. The median household income of the district was $51,916. Table 3-1 gives the ethnic breakdown of Lone Peak as of 2006. It had a graduation rate of 90.41%. Eight percent of the students qualified for free or reduced lunches. The student to teacher ratio was 25:1 in 2005, compared to a state average of 23:1. The average ACT score in 2006 was 22.9 while the Utah state average was 21.7.

Table 3-1: Lone Peak Student Body Composition

Ethnic Group	Percentage
Caucasian	96%
Hispanic	2%
Asian/Pacific Islander	1%
African American	<1%
American Indian/ Alaskan Native	<1%

The courses were taught using a "block" schedule which consisted of 84 minute classes every other day (students would have physics three days some weeks and only two days other weeks). The first, second and third period classes would take place before lunch with fourth period being the only class after lunch.

The instructor had two previous years of teaching experience, both at Lone Peak High School. During those two years he taught the same physics course about which this study was conducted (taught with the guided inquiry approach), a semester long astronomy course, and for one previous year a more conceptually based physics course called Physics with Technology. He had a bachelor's degree in physics (2005) and a physics teaching endorsement (2005).

3.3 Research Design

The teaching approach for each of the instructor's four sections of introductory high school physics was randomly determined (Table 3-2) to be guided-inquiry for periods three and four and open-inquiry for periods one and two. As student performance could be affected by class period, random assignment of treatments added to the validity of the study. The guided-inquiry classes followed the Modeling Instruction Program (MIP) developed at Arizona State University, while the open-inquiry classes were based on an approach used by Wolff-Michael Roth, at Simon Fraser University. Roth's open-inquiry approach to teaching introductory physics to junior and senior level boys at a private school in central Canada is documented in several articles and books (Roth 1994).

Table 3-2: Random Class Treatment Selection

Number on Die	Possible Classroom Configurations	Total Rolls (100)
1	Open Inquiry – periods 1 and 2 Guided Inquiry – periods 3 and 4	26
2	Open Inquiry – periods 1 and 3 Guided Inquiry – periods 2 and 4	14
3	Open Inquiry – periods 1 and 4 Guided Inquiry – periods 2 and 3	12
4	Open Inquiry – periods 2 and 3 Guided Inquiry – periods 1 and 4	15
5	Open Inquiry – periods 2 and 4 Guided Inquiry – periods 1 and 3	15
6	Open Inquiry – periods 3 and 4 Guided Inquiry – periods 1 and 2	18

3.3.1 Guided Inquiry Classroom

Though the instructor did not have formal training in the MIP methodology, both his student-teaching supervisor and his mentor teacher during his first two years at Lone Peak High School had participated in MIP training workshops and were current practitioners of the approach. The first units of the curriculum are found in Table 3-3.

Table 3-3: MIP Curriculum
(Modeling Instruction Program, 2002)

Unit 1	Scientific Thinking
Unit 2	Constant Velocity
Unit 3	Constant Acceleration
Unit 4	Free Particle (Balanced Forces)
Unit 5	Constant Force (Net Force)
Unit 6	2-Dimensional Kinematics

MIP is a self-contained high school physics curriculum that does not accompany any textbook. The word "modeling" in MIP is not to be confused with the teaching method known as modeling, where the teacher "models" behavior for the students. Instead it refers to the idea that phenomena can be modeled, or represented, in several ways (e.g. as a picture, as a graph, as an equation, etc.). One of the overarching principles in the structure of the MIP approach is to help students recognize that all of these representations are equivalent. This is done through labs which introduce new concepts and are designed to shift thinking towards a Newtonian paradigm. Lab reports, homework problems, tests, and the sharing of results through a process termed white-boarding, are other foundational elements of the course.

The nature of the MIP labs and their placement at the beginning of the unit are both aspects of guided inquiry that contrast with traditional physics classrooms. With the lab experience before a formal introduction to a new concept, students can connect the new ideas presented with an actual phenomenon that they have experienced. Almost every equation used in the course is derived from the students' actual lab data, rather than being materialized ex nihilo. While the teacher does have a set research question in mind for each lab, the students are lead to identify the relevant variables themselves (through brainstorming and evaluating significant factors influencing a given phenomenon) and are given substantial liberty in choosing the methods used to answer the research question. Individual lab reports help each student to be accountable for understanding and communicating the purpose, methods, and findings of the lab.

About 20-30% of class time is spent in the lab with the majority of the remaining time used for working through a number of worksheets that are generally focused on computation. Unit tests (given every 2-3 weeks) very closely resemble the homework but often include selected conceptual questions that address the ideas brought forth in the lab.

Another integral piece of the MIP curriculum is white-boarding. So named because small white-boards (approximately 2 feet by 3 feet) are used by groups of students to organize and present their findings to each other. This is done to discuss the data and conclusions after each lab. Included are a graph, an equation, and an explanation of the relationship(s) found. It also plays a central role in working through homework problems. Generally each group is given a different problem from the assignment and the students present solutions and answer questions from classmates as well as the teacher. The presenting students must have a good understanding of the problem in order to coherently explain it to others and the receiving students can at times gain a clearer understanding from a peer's explanation than from that of a teacher.

3.3.2 Open Inquiry Classroom

To summarize the difference in the two classrooms, the open-inquiry approach had the allotment of class time on labs and homework swapped with that of the guided-inquiry approach. Preparing for, performing, or analyzing labs accounted for 60-70% of the total class time. The rest of the time was spent sharing experimental results, concept mapping, and taking tests. Textbook problems were also given as homework. The same content used in the MIP curriculum also set the framework for the open-inquiry classroom.

Another major difference was that the students were responsible for generating their own research questions within the context of the unit. Things looked very similar to the MIP class for the first lab of the unit as the teacher provided suggestions for investigations, though students did ultimately have the choice of their research question. But this was used as a starting off point, where questions arising in the first lab would lead to an additional lab or two (depending on the unit) where the students supplied the relationship to be studied and the methodology used. This meant that it was possible for every group to be working on a different lab. The teacher was available as a resource in the formulation of research questions, but care was taken to support the students in solidifying their own thoughts rather than supplying ideas for them. Occasionally the instructor felt that a lab was just not feasible and recommended trying something else. The labs would generally take two to three class periods to complete: 45-60 minutes formulating the question and planning the data collection, 80-130 minutes collecting and analyzing data, and 45-60 minutes discussing results with the teacher and fellow students as conclusions were formed.

Lab reports were submitted in groups. Because of the nature of the student-centered lab experience (it was possible that an experiment did not lead to a conclusion other than that the given approach was not successful), the grading of lab reports focused on logical consistency and feasibility of interpretations of data. About one period every two weeks was used for class discussions which included presentations of laboratory findings, reviewing, or introducing new tools or instruments (force meters, computer programs, etc.). As groups presented their lab design, results, and conclusions to the class, each lab would be related back to the common themes fundamental to the current unit of study.

Students were also required to complete 6 homework problems of their choosing each week and concept maps summarizing the entire unit. The homework problems were to be completed individually, but the concept maps were again a group assignment. This often led to valuable exchanges between students as they helped each other articulate their understanding of the relationships between the concepts of a given unit. Unit tests were given less frequently than in the guided-inquiry approach and counted as a smaller portion of the students' overall grade. The tests were originated by the teacher and were written to reflect the focus of the class, asking the students to analyze and interpret data tables and graphs similar to what they encountered in their lab experiences.

A main goal of the open-inquiry approach was to give the student as much responsibility over their learning as possible, yet still retain enough structure for the class to be coherent and to hold the students accountable. Also the focus is shifted from spending most of the time working on foundational knowledge with the occasional project to address higher-order learning, to the majority of the time being concentrated on analytical and reasoning skills.

3.4 Data and Instrumentation

The independent variable in this study was the level of inquiry, or student-centeredness, of the high school physics class. The dependent variables of interest were the students' short-term (immediately following instruction on all concepts) and long-term (10-11 weeks later) understanding of introductory physics concepts as well as the student's attitudes towards physics. To assess these outcomes, the following instruments were employed:

1. The Force Concept Inventory (FCI) – a 30 question multiple choice conceptual exam widely used as baseline measurement of understanding of Newtonian physics. Short-term and long-term physics understanding was assessed with the FCI (Hestenes, 1992).
2. Utah State Criterion Referenced Physics Test (CRT) – a 70 question multiple choice test covering a broader range of topics than what is found on the FCI. It is mostly conceptual but includes some minor computational questions. This was used to assess short-term understanding and to validate the results of the FCI.
3. Colorado Learning Attitudes about Science Survey (CLASS) – a 42 question Likert scale (agree-disagree) survey to measure students' attitudes towards physics. (Adams et al., 2006; Appendix C)

The FCI was given three times during the course of the year. A pretest was given at the beginning of the year in order to later calculate gain scores. A posttest was given during the third quarter of the year after all concepts addressed on the FCI had been covered. The first test was given without a review and counted only minimally on the students' grades. On the last day of the year, a second posttest was given as the course final. Content was reviewed prior to the second posttest and students' scores were a significant part of their grade. As the material covered on the FCI was not explicitly taught between the first and second posttests, the second posttest was intended as a measure of retention. The CRT was administered throughout the state of Utah near the end of the school year. This was used as an additional measure of the learning of Newton's Laws, as well as additional physics topics. The CRT also influenced students' grades significantly. The CLASS was used at the beginning of the year and again at the time of the first FCI posttest to investigate changes in students' attitudes towards physics.

3.5 Analysis of Data

Both practical and statistical significances were considered in comparing the differences in outcomes for the two instructional approaches. Only scores from students who remained in a single treatment for the whole year were included in the data. This excluded students who moved in or transferred from another class part way through the year as well as students who switched from one treatment to the other. A total of 44 students in the open-inquiry class and 42 in the guided-inquiry took the FCI all three times as well as the CRT while remaining in the same treatment for the entire school year. The pre and post CLASS was completed by 40 open-inquiry and 41 guided-inquiry students. Fewer students were included in the CLASS results due to absence and incorrect responses to a questions designed to identify those who did not actually read the survey. When comparing scored responses on the exams (FCI and CRT) an F-test was employed to confirm equal sample variances followed by a two-tailed t-test of sample means assuming equal variances with an alpha level of .05. A two-tailed test was chosen because it was important to see if the test scores of students experiencing the open-inquiry approach were statistically higher or lower than the scores of students undergoing the guided-inquiry method. The results of the survey were analyzed with a spreadsheet provided by Adams et al. (2006) and conclusions were made interpretively rather than on a test of significance. Subtests of the FCI and CRT consisting of a subset of questions applying to a given concept were also examined.

For the FCI test average raw gain scores (‹G›, equation 3-1) were calculated for each of the two posttests as well as normalized gain scores (‹g›). The normalized gain score measures how many more questions a student answered correctly on a posttest out of how many they could have possibly improved by. Because the FCI is a 30 question test, the normalized gain was calculated using equation 3-2. An advantage of this method of examining a gain score is that it removes the limitation on the gain score of a student who does well on the pretest. For example, if students A and B both had raw gain scores of 10 points on the FCI, but student A scored a 10 on the pretest and student B a 20, then their raw gain scores would be equal but their normalized gain scores would be quite different. Student A would have a normalized gain score of .5 (he correctly answered half of the questions that he had missed the first time) whereas student B would have a normalized gain score of 1 (he gained all points he possibly could). Hake (1998) interpreted <g> scores for the FCI as low if $\langle g \rangle < .3$, medium if $.3 \leq \langle g \rangle < .7$, and large if $\langle g \rangle \geq .7$ (p. 65). A t-test was applied to the raw scores on both FCI post tests, as well as the raw and normalized gain scores. The CRT test could only be given once throughout the year which limited the analysis to a t-test of sample means.

$$< G >= post - pre \qquad \textbf{(3-1)}$$

$$< g >= \frac{post - pre}{\max - pre} = \frac{post - pre}{30 - pre} \qquad \textbf{(3-2)}$$

An additional way of evaluating the results of the FCI was to look at the percentage of students scoring at or above 18, the score chosen by the creator of the test (Hestenes et al., 1992) as the threshold of those who have successfully achieved thinking in a Newtonian paradigm. As there were no students who scored at the Newtonian threshold on the pretest, percentages of students scoring above 18 on the posttests were compared as well as the change in that percentage from the first posttest to the second.

With the relatively small sample sizes in this study, large differences in scores would be needed to claim statistical significance. For that reason practical significance in the form of effect sizes (*d*) were also considered in analyzing the results of the FCI and CRT. The effect size is defined as a difference in sample means expressed in numbers of pooled standard deviations. The effect size (*d*) is calculated using equation 3-2, which is independent of the sample size. Though somewhat subjective, a commonly used scale for the interpretation of an effect size is 0.20 for small significance, 0.50 for medium significance, and 0.80 for large significance (Cohen, 1988).

$$d = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{(\sigma_1^2 + \sigma_2^2)/2}} \qquad \textbf{(3-3)}$$

The CLASS uses a 5-point Likert scale of the strength of agreement or disagreement with each statement. An “expert opinion” has been determined for 36 of the 42 survey questions (Appendix D) and responses were viewed as either agreeing or disagreeing with the expert. To agree with the expert meant to disagree with some statements but to agree with others. This meant that it was not possible to sum the responses from each treatment to determine the degree to which attitudes towards physics had changed. An additional challenge to analyzing the survey was having “neutral” as a possible response. When comparing the pre and post-surveys, one could have fewer students choose the neutral option and potentially have a higher percentage of students agree with the expert opinion at the same time that a higher percentage of students disagree. The most positive change was seen then as an increase in the percentage of students agreeing with the expert opinion accompanied by a decrease in the percentage of students disagreeing.

4 Findings

The researcher was interested in comparing knowledge of physics content as measured by raw test scores and gain scores, and attitudes towards physics for students participating in open-inquiry (Roth) and guided-inquiry (MIP) high school physics courses. The results are grouped by measurement instrument.

4.1 FCI Results – Measure of conceptual understanding of force and motion

4.1.1 Pretest

The first time the students in both treatments took the FCI was on the second day of school (23 August). No instruction related to forces or motion had been given to either class prior to the test being administered. The average scores for the open and guided-inquiry classes were 7.8 and 7.2 respectively with standard deviations of 3.3 and 3.0 (Table 4-1). The open-inquiry classes had a maximum score of 16 and a minimum score of 2, while the maximum and minimum for the guided-inquiry classes were 14 and 3, respectively. As evinced by the already mentioned maximum scores, no students in either treatment scored at or above the Newtonian threshold of 18. F and t-tests showed no statistically significant difference in the sample variations or means.

Table 4-1: FCI Pretest Results

	Open	Guided	Difference	p-value
Mean	7.8	7.2	0.6	0.41
σ	3.3	3.0	0.3	0.24

4.1.2 Posttest 1

Due to slight variations in pacing arising from the differences in instructional methods, the first posttest was not administered on the same day for all classes, though for both treatments it was immediately after completing the material that is addressed on the FCI. The two sections of open-inquiry physics took the first posttest on 12 March and the guided-inquiry physics sections took it on 20 March. No class time was taken to review for the test nor were any review materials supplied to the students.

Raw Scores

The average posttest score for the open-inquiry classes was 13.7 (out of 30) and that of guided-inquiry classes was 14.7 with standard deviations of 5.1 and 5.3, respectively (Table 4-2 and Table 4-3). While these mean scores seemed low with large standard deviations, these results were similar to those reported by Adams (1997) and did represent rather normal distributions (Figure 4-1). The FCI contains very well written distracters that accurately represent common misconceptions. For a student to perform well, he must have a highly developed understanding of the fundamental principles governing force and motion. The open-inquiry classes had a maximum score of 23 and a minimum score of 3, while the maximum and minimum for the guided-inquiry classes were 24 and 4, respectively. Regarding the Newtonian threshold, 18% of the open-inquiry physics scored at least an 18 compared to 29% of the guided-inquiry students. An F-test showed no statistically significant difference in variance. A t-test showed the 1 point difference in sample means to also lack statistical significance with a two-tailed p-value of .38. The effect size of the difference in mean scores between the two treatments was .19, below the .20 threshold to even be considered of small significance and barely higher than the *d* of .18 for the difference in pretest means.

Table 4-2: FCI Posttest 1 - Analysis of Means

	Open	Guided	Difference	p-value	*d*
Mean	13.7	14.7	-1.0	0.38	-0.19
‹G›	6.0	7.5	-1.5	0.11	-0.34
‹g›	0.27	0.33	-0.06	0.17	-0.29

- Difference - open-inquiry score subtract guided-inquiry score - a negative value indicates lower scores for the open-inquiry treatment.
- *d* - effect size – a negative value indicates the open-inquiry score was lower than the guided-inquiry score.
- ‹G› - Raw gain scores (posttest-pretest)
- ‹g› - Normalized gain score (‹G›/possible ‹G›)

Table 4-3: FCI Posttest 1 - Analysis of Distributions

	Open	Guided	Difference	p-value
σ (mean)	5.1	5.3	-0.2	0.38
σ (‹G›)	4.2	4.8	-0.6	0.18
σ (‹g›)	0.19	0.22	-0.03	0.19

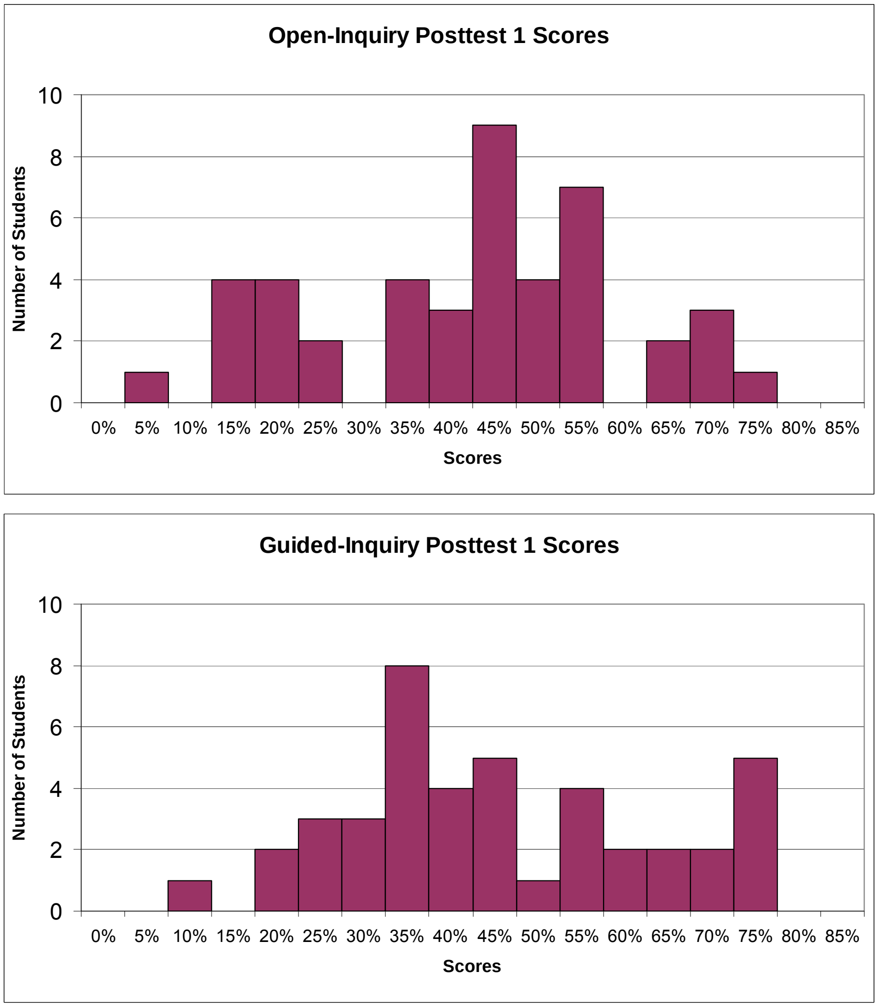

Figure 4-1: Distributions of FCI Posttest 1 Scores

Raw Gain Scores

The open-inquiry classes had an average gain score (‹G›) of 6.0 and the guided-inquiry class had an average ‹G› score of 7.5. The maximum gain scores for the open and guided-inquiry coursed were 15 and 21 respectively while the minimum gain scores were -5 and -3 (indicating a lower score on the posttest than on the pretest). Again this is a fairly common result for the FCI, where students whose learning remains at a surface level will likely show little to no improvement. Standard deviations were 4.2 and 4.8 for the open and guided-inquiry treatments. No statistical significance was found in any of these differences, but a two-tailed t-test of mean gains had a lower p-value (.11) than that of the t-test for mean scores. The difference in average ‹G› scores does represent a *d* (effect size) of .34, a value near the middle of the range of small significance.

Normalized Gain Scores

The average ‹g› (normalized gain) scores for the open and guided-inquiry classes were .27 and .33, respectively. These normalized gain scores straddle the cutoff between low and medium gains for the FCI with the open-inquiry scores just below and the guided-inquiry scores just above. The separate approaches had standard deviations of .19 and .22, maxima of .65 and .78, and minima of -.23 and -.13. None of these differences were statistically significant. Analysis of the effect size again showed a small practical significance with a *d* of .29.

4.1.3 Posttest 2

The third time that the FCI was given was on the last class of the year (either 27 or 29 May depending on the finals schedule) for both the open-inquiry and the guided-inquiry courses. Between 10 and 11 weeks had passed since the first posttest, during which time no teacher instruction directly of forces or motion was given, but the concepts covered on the FCI were reviewed identically with all classes on two occasions: once with an online practice test completed in groups during class to prepare for the CRT, and a second time with student groups presenting concepts outlined on a review sheet (0) supplied by the instructor in preparation for the final (the second FCI posttest). The online practice test gave immediate feedback on whether or not the question was answered correctly while the instructor was available to the students for further explanation as needed. Raw and normalized gain scores for the second posttest were calculated by comparing to pretest scores.

Raw Scores

The average score for the open-inquiry classes was 16.4 and that of guided-inquiry classes was 15.7 with standard deviations of 6.2 and 5.2, respectively (Table 4-4 and Table 4-5). Again the distributions of scores for both classes were quite normal (Figure 4-2). The open-inquiry classes had a maximum score of 27 and a minimum score of 3, while the maximum and minimum for the guided-inquiry classes were 26 and 6, respectively. Regarding the Newtonian threshold, 48% of the open-inquiry physics scored at least an 18 compared to 45% of the guided-inquiry students. An F-test showed no statistically significant difference in variance. A t-test showed the .7 point difference in sample means to also lack statistical significance with a two-tailed p-value of .58. The effect size of the difference in mean scores between the two treatments was .12, well below the .20 threshold to even be considered of small significance.

Table 4-4: FCI Posttest 2 - Analysis of Means

	Open	Guided	Difference	p-value	*d*
Mean	16.4	15.7	0.7	0.58	0.12
‹G›	8.7	8.5	0.1	0.90	0.03
‹g›	0.40	0.38	0.02	0.62	0.11

- Difference - open-inquiry score subtract guided-inquiry score - a negative value indicates lower scores for the open-inquiry treatment.
- *d* - effect size – a negative value indicates the open-inquiry score was lower than the guided-inquiry score.
- ‹G› - Raw gain scores (posttest-pretest)
- ‹g› - Normalized gain score (‹G›/possible ‹G›)

Table 4-5: FCI Posttest 2 - Analysis of Distributions

	Open	Guided	Difference	p-value
σ (mean)	6.2	5.2	1.0	0.13
σ (‹G›)	5.0	4.5	0.5	0.27
σ (‹g›)	0.24	0.20	0.03	0.16

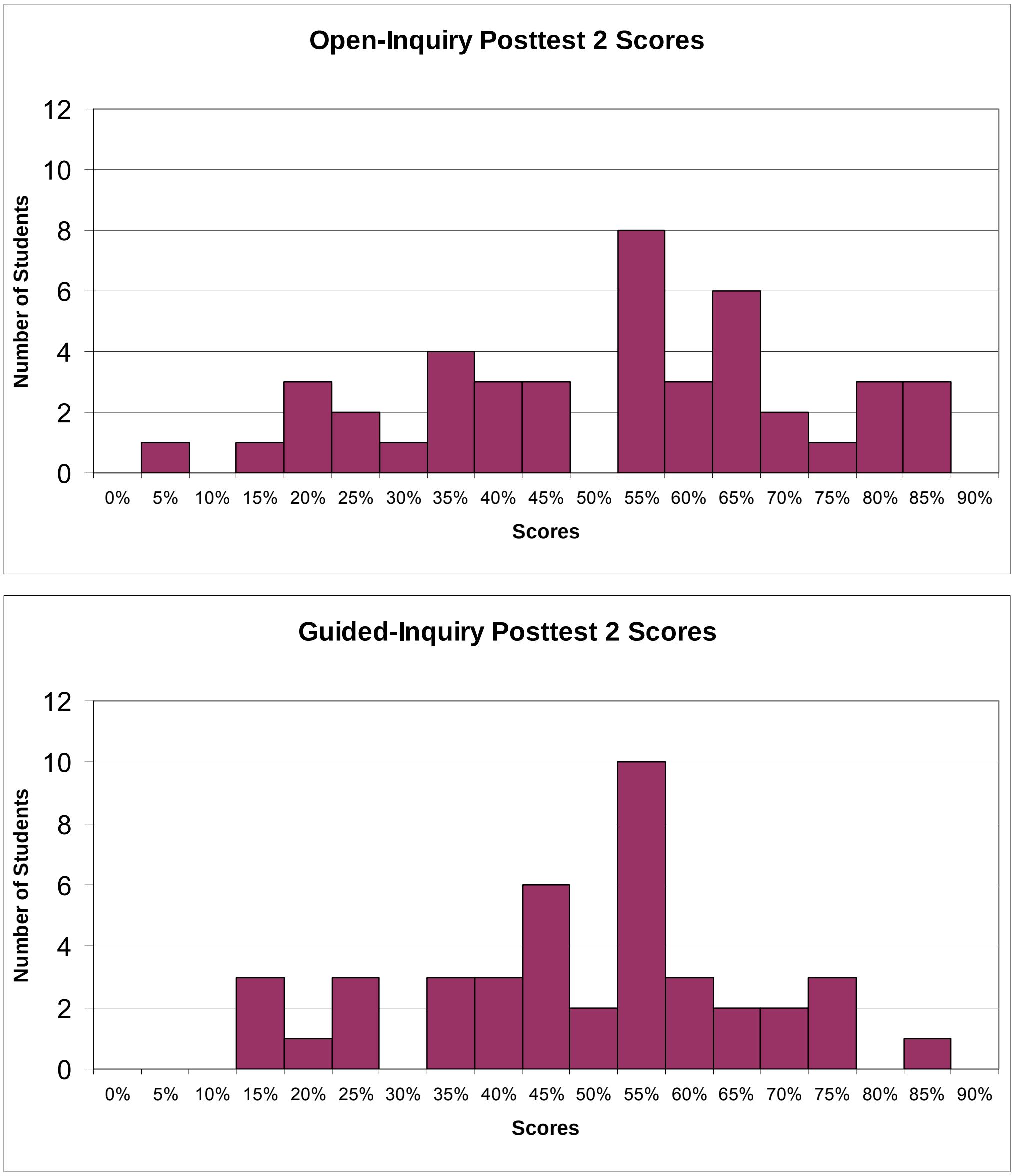

Figure 4-2: Distributions of FCI Posttest 2 Scores

Raw Gain Scores

The open-inquiry classes had an average ‹G› score of 8.7 and the guided-inquiry class had an average ‹G› score of 8.5. The maximum gain scores for the open and guided-inquiry coursed were 18 and 19 respectively while the minimum gain scores were both -3. Standard deviations were 5.0 and 4.5 for the open and guided-inquiry treatments. Again no statistical significance was found in any of these differences. The difference in average ‹G› scores represents a *d* of only .03.

Normalized Gain Scores

The average ‹g› scores (actual increase divided by maximum possible increase) for the open and guided-inquiry classes were .40 and .38, respectively. These ‹g› scores both fall in the range of medium gain scores for the FCI. The separate approaches had standard deviations of .24 and .20, maxima of .82 and .78, and minima of -.13 and -.14. None of these differences were statistically significant. Analysis of the effect size again showed no indication of practical significance with a *d* (effect size) of .11.

4.1.4 Comparing Posttests 1 and 2

The results of the second posttest were somewhat surprising to the researcher in that they indicated continued improvement rather than measuring retention. For this reason the gain scores between posttest 1 and posttest 2 were of particular interest.

Raw Gain Scores

The open-inquiry classes had an average ‹G› score of 2.7 and the guided-inquiry class had an average ‹G› score of 1.0 (Table 4-6 and Table 4-7). The maximum gain scores for the open and guided-inquiry coursed were both 8 while the minimum gain scores were -3 and -5, respectively. Standard deviations were 2.8 and 3.1 for the open and guided-inquiry treatments. The difference of 1.7 in the average gain scores was definitively found to have statistical significance with a p-value of .010 as well as having practical significance in the medium range with a *d* of .57. The percentage of students in the open-inquiry class reaching the Newtonian threshold increased 30% from one posttest to the next compared to 17% of the guided-inquiry students.

Table 4-6: FCI Posttests 1 and 2 - Analysis of Mean Gains

	Open	Guided	Difference	p-value	*d*
‹G›	2.7	1.0	1.7	0.010	0.57
‹g›	0.20	0.04	0.16	0.002	0.69

- Difference - open-inquiry score subtract guided-inquiry score - a negative value indicates lower scores for the open-inquiry treatment.
- *d* - effect size – a negative value indicates the open-inquiry score was lower than the guided-inquiry score.
- ‹G› - Raw gain scores (posttest-pretest)
- ‹g› - Normalized gain score (‹G›/possible ‹G›)

Table 4-7: FCI Posttests 1 and 2 - Analysis of Distributions

	Open	Guided	Difference	p-value
σ (‹G›)	2.8	3.1	-0.2	0.32
σ (‹g›)	0.20	0.25	-0.04	0.11

Normalized Gain Scores

The average ‹g› scores for the open and guided-inquiry classes were .20 and .04, respectively. The two treatments had standard deviations of .20 and .25 (Table 4-7), maxima of .70 and .47, and minima of -.14 and -.83. Strong evidence of a difference in average ‹g› scores was found. A t-test gave a statistically significant p-value of .002. A *d* of .69 was calculated, a value approaching high practical significance.

4.1.5 FCI Subtests

Each of the 30 questions on the FCI was assigned to one of six concepts to consider if one treatment appeared to teach certain ideas more effectively than the other treatment. These categories and pretest, posttest 1, and posttest 2 scores as a percentage of correct responses are shown in Figure 4-3 and Figure 4-4. A definite adjustment period for the open-inquiry class to be comfortable with the increased autonomy was noted, yet the instructor felt that it was about 2 months rather than the 3-4 months observed by Roth (2007). Some instruction on all categories except “circular motion’ and “projectiles” was given during this time period.

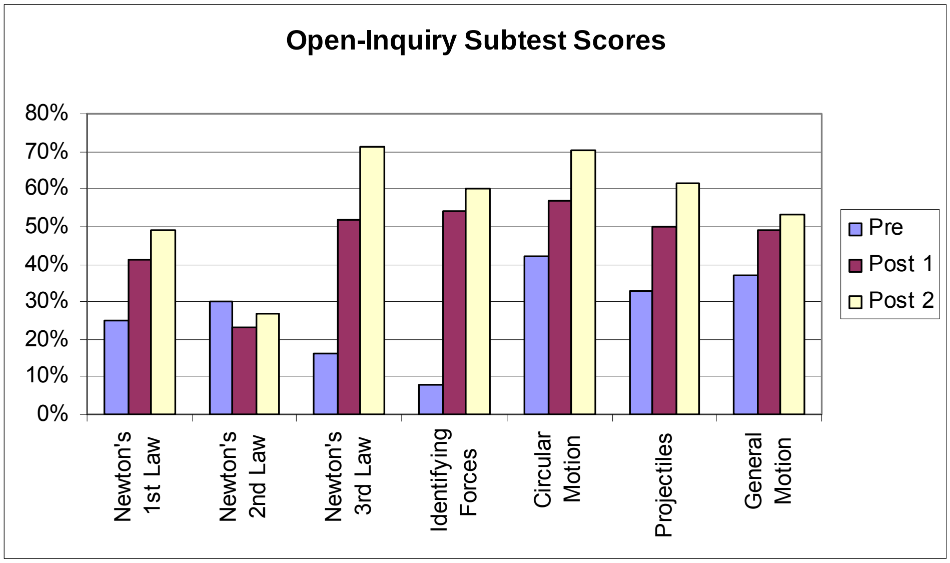

Figure 4-3: Open-inquiry FCI Pretest, Posttest 1, and Posttest 2 Subtest Scores

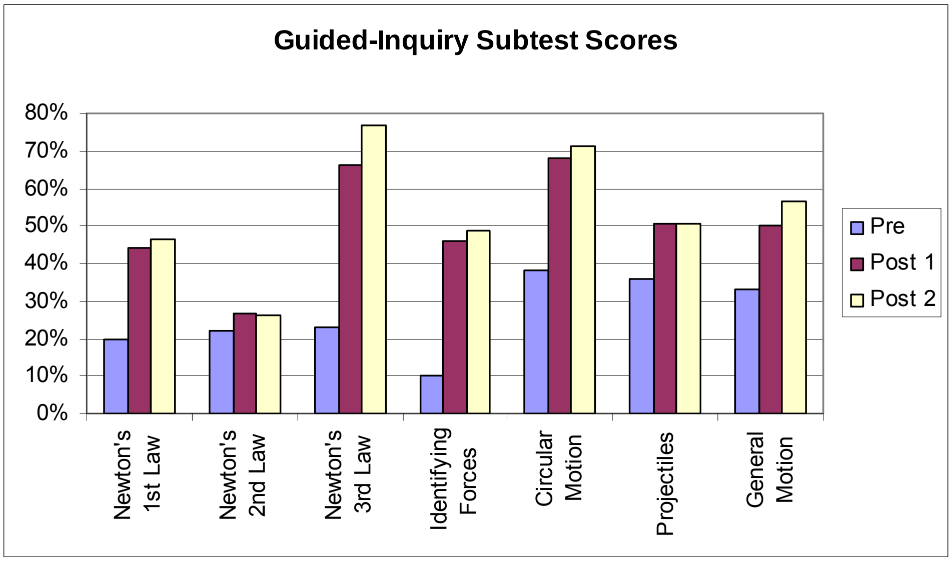

Figure 4-4: Guided-inquiry FCI Pretest, Posttest 1, and Posttest 2 Subtest Scores

While most categories increased with each subsequent test administration, Newton's second law was a notable exception. For the open-inquiry class, neither posttest score achieved the level of the pretest score. While the posttest scores of the guided-inquiry class did exceed the pretest score, it was the only category with a decline between posttest 1 and posttest 2. Scores on questions regarding projectiles for the guided-inquiry treatment remained level from one posttest to the next.

Comparing the final (posttest 2) subtest scores for each treatment (Figure 4-5) shows that while the open-inquiry students ended up with a slightly higher overall mean score, the guided-inquiry class had superior scores in three of the seven subcategories. The largest differences between the two treatments were found in the “identifying forces” and “projectiles” categories, with the open-inquiry class scoring 11% higher in both instances.

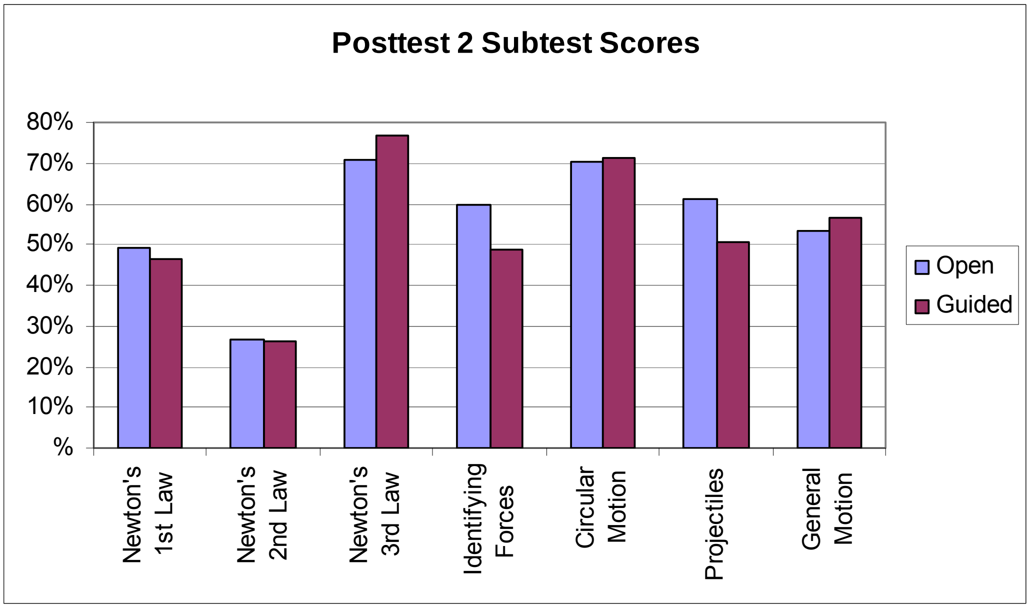

Figure 4-5: Comparison of Posttest 2 Subtest Scores

4.2 CRT Results – State core test of physics knowledge

The CRT was a 70-question computer-based test that was administered to all classes on 28 April. This test generally covered the same concepts as the FCI (force and motion), but also included questions on waves, energy, scientific procedures, and specific questions about gravitational and electric forces. Though largely a conceptual test, the CRT also asks students to interpret data in the form of tables and graphs as well as to make rudimentary mathematical calculations. Scores are reported by the state to the instructor and include class averages and an analysis of subtests aligned with the state core curriculum.

4.2.1 Mean Scores

The mean score for students from open-inquiry classes was 52.0 while the mean for students from guided-inquiry classes was 47.7 (Table 4-8). In 2007, a score above 42 was considered proficient (or passing) and above 51 was classified as highly proficient. The state-wide average score was 44.1 and the average of the district of which Lone Peak is a part was 45.5. Standard Deviations were 9.7 and 10.0, respectively. An F-test showed no evidence of unequal variance so a two-tailed t-test of sample means assuming equal variance was used. A p-value of .049 was just slightly less than the alpha of .05 and indicated that there was significant statistical evidence that the mean of the scores from open-inquiry students was higher than the mean of the scores from guided-inquiry students. A *d* (effect size) calculated at .43 was indicative of a medium level of practical significance. Multi-modal distributions were observed in both treatments (Figure 4-6).

Table 4-8: CRT Means and Standard Deviations

	Open	Guided	Difference	p-value	*d*
Mean	52.0	47.7	4.2	0.049	0.43
σ	9.7	10.0	-0.4	0.403	n/a

- Difference - open-inquiry score subtract guided-inquiry score - a negative value indicates lower scores for the open-inquiry treatment.
- *d* - effect size – a negative value indicates the open-inquiry score was lower than the guided-inquiry score.

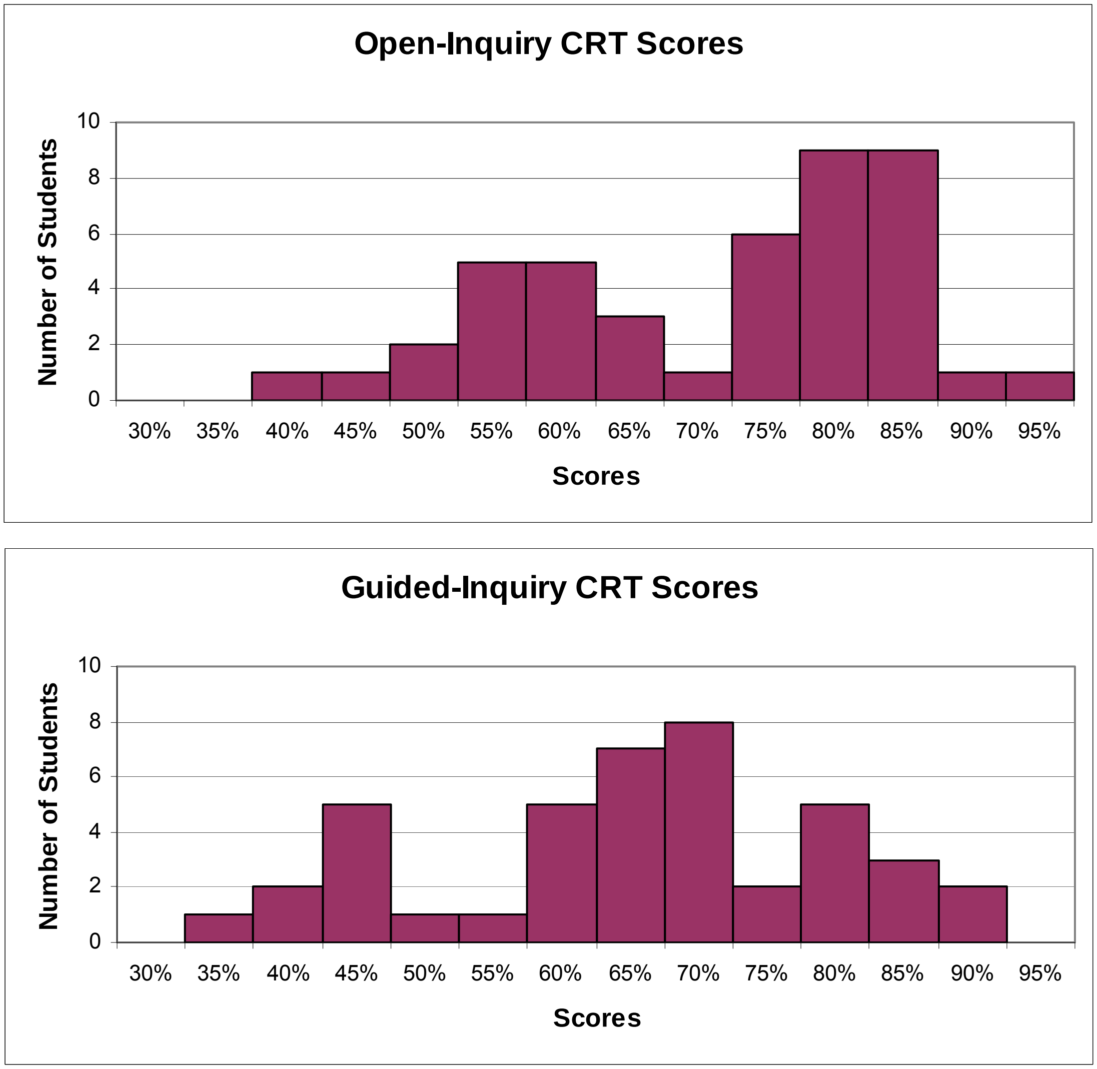

Figure 4-6: CRT Score Distributions

4.2.2 Subtests

The state of Utah assigned each question on the physics CRT to one of five categories known as standards (Table 4-9). Scores calculated as a percentage of correct responses to questions for each standard are shown in Figure 4-7. Not only did the open-inquiry classes have a higher overall average, they also scored higher in every subtest. The discrepancy was smallest for questions relating to gravitational and electric forces and largest for questions relating to energy.

Table 4-9: Utah State Core Standards

Standard I	How to measure, calculate & describe the motion of an object
Standard II	Relationship between force, mass & acceleration
Standard III	Factors determining strength of gravitational & electric forces
Standard IV	Transfer & conservation of energy
Standard V	Properties & applications of waves

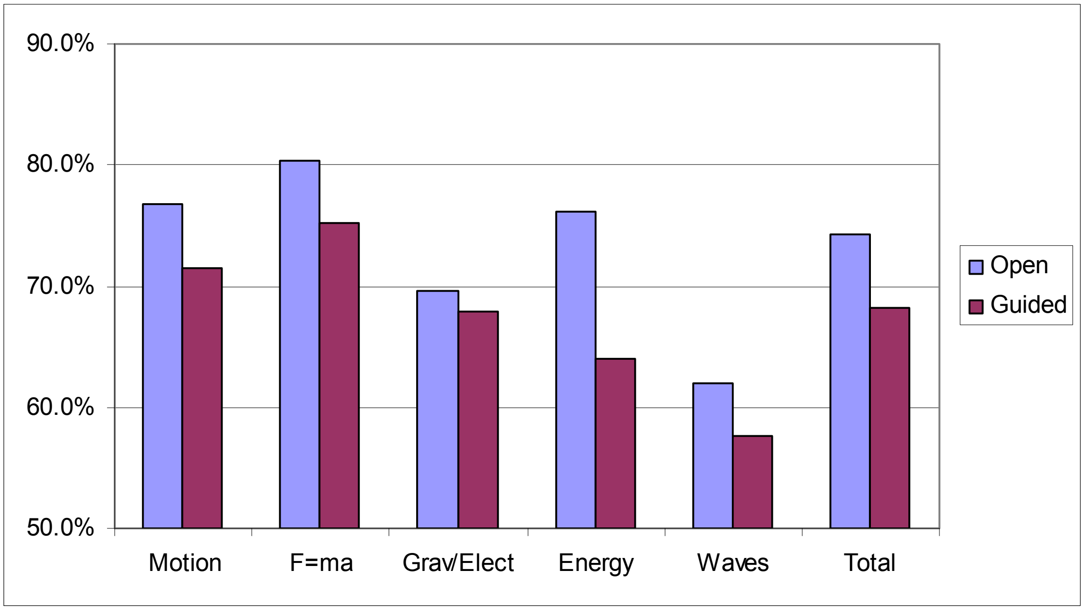

Figure 4-7: CRT Subtest Scores

4.3 CLASS Results – Physics Attitudes Survey

The Colorado Learning Attitudes about Science Survey was first given to all classes during the second week of school (31 August). It was given for the second time on 18 March for the open-inquiry classes and on 26 March for the guided-inquiry classes. As with the second FCI test, the different dates of administration were a result of variations in class pacing, but the surveys were given at the same point in the curricular sequence.

Of the 42 questions on the test, one question is designed to help identify those who are not reading the test by instructing them to give a certain response, 36 questions had established "expert responses" with which to compare student responses, and 26 questions were grouped into one or more sub-categories (Appendix E) that were established by Adams et al. (2006) for more detailed analysis.

When considering all 36 established questions, the open-inquiry class increased in the percentage of students who agree with the expert opinion (Figure 4-8) as well as the percentage of students who disagree with the expert opinion (Figure 4-9). This indicates that there were less "neutral" responses. After treatment with the guided-inquiry teaching approach, students were less likely to agree with the expert opinion and slightly less likely to disagree.

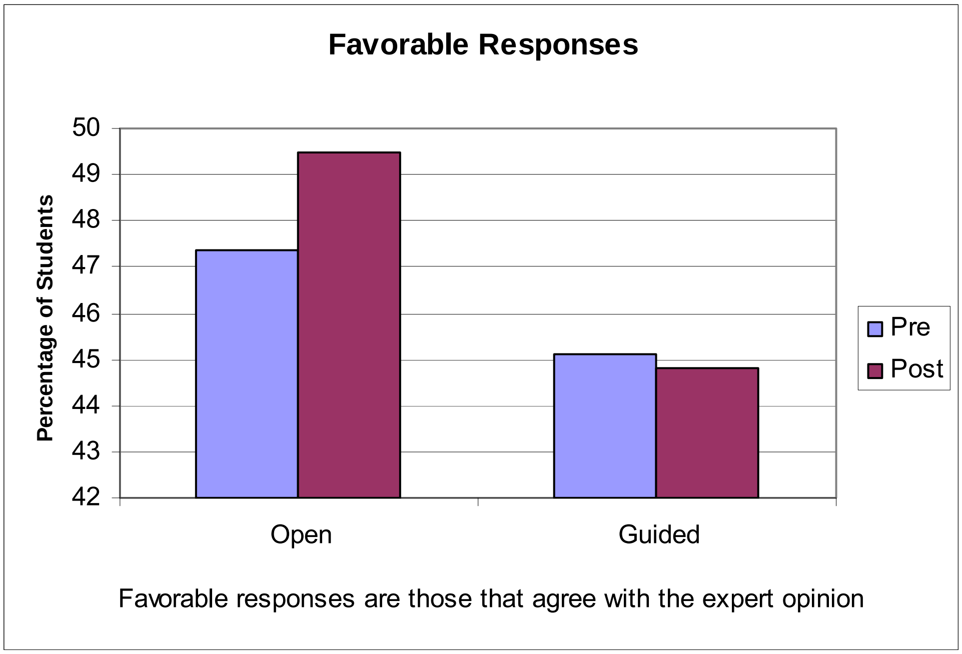

Figure 4-8: Pre/Post CLASS Favorable Responses

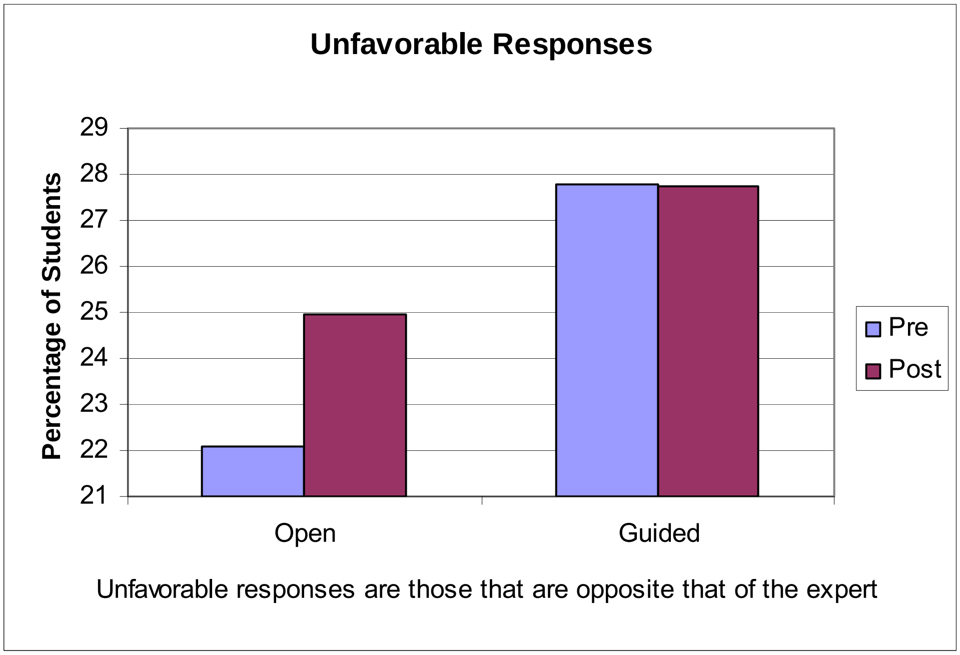

Figure 4-9: Pre/Post CLASS Unfavorable Responses

Comparing the magnitude of these shifts showed that the largest change was in those open-inquiry students who disagreed with the expert (Figure 4-10). It also appeared that there was much greater movement in the opinions of the students experiencing open-inquiry than those experiencing guided inquiry.

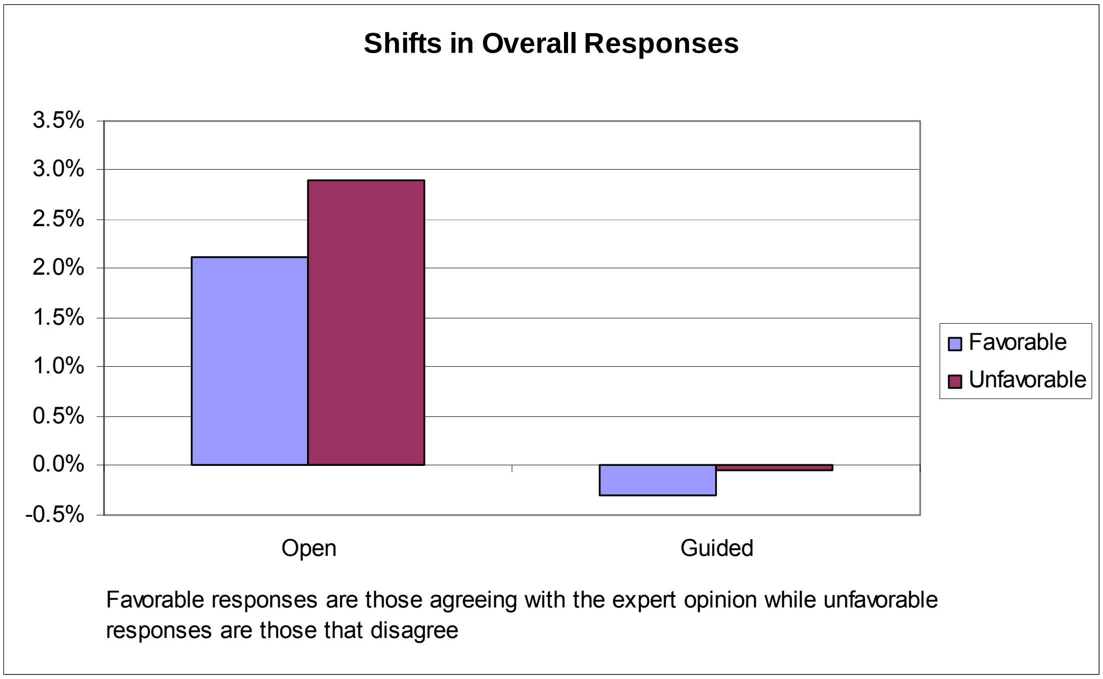

Figure 4-10: Overall Shifts in CLASS Responses

Conclusions about the results of the survey required the shifts in favorable and unfavorable opinions to be considered simultaneously. To accomplish this, normalized shifts were calculated as a percentage of possible positive change in opinion (either more agreement with the expert or less disagreement). The sign of the shifts in unfavorable opinions were chosen to have positive values reflect a positive result (less disagreement with the expert). Normalized movements of opinions were also disaggregated into each of the sub-categories of the survey (Figure 4-11 and Figure 4-12). Using these plots allowed results to be characterized by the quadrant in which a data point is found. The first quadrant is evidence of an overall positive movement in opinions, the third quadrant indicates a negative movement, while second and fourth quadrant data is less conclusive with both favorable and unfavorable responses either increasing or decreasing together.

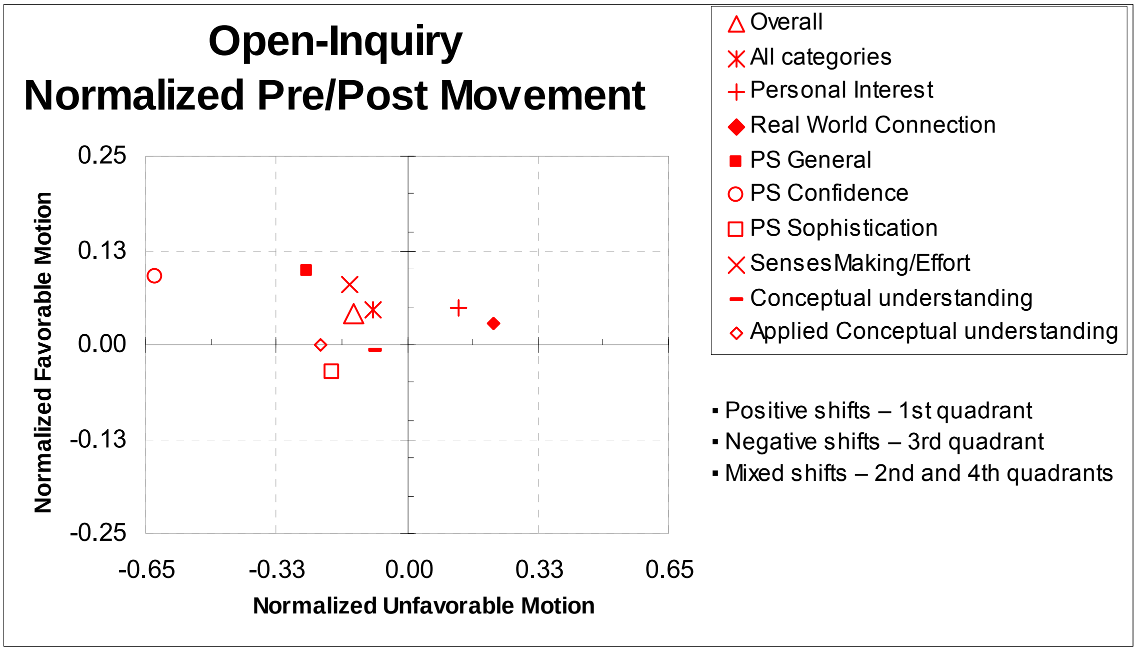

Figure 4-11: Shifts in Opinions of Open-inquiry Students by Subcategory.

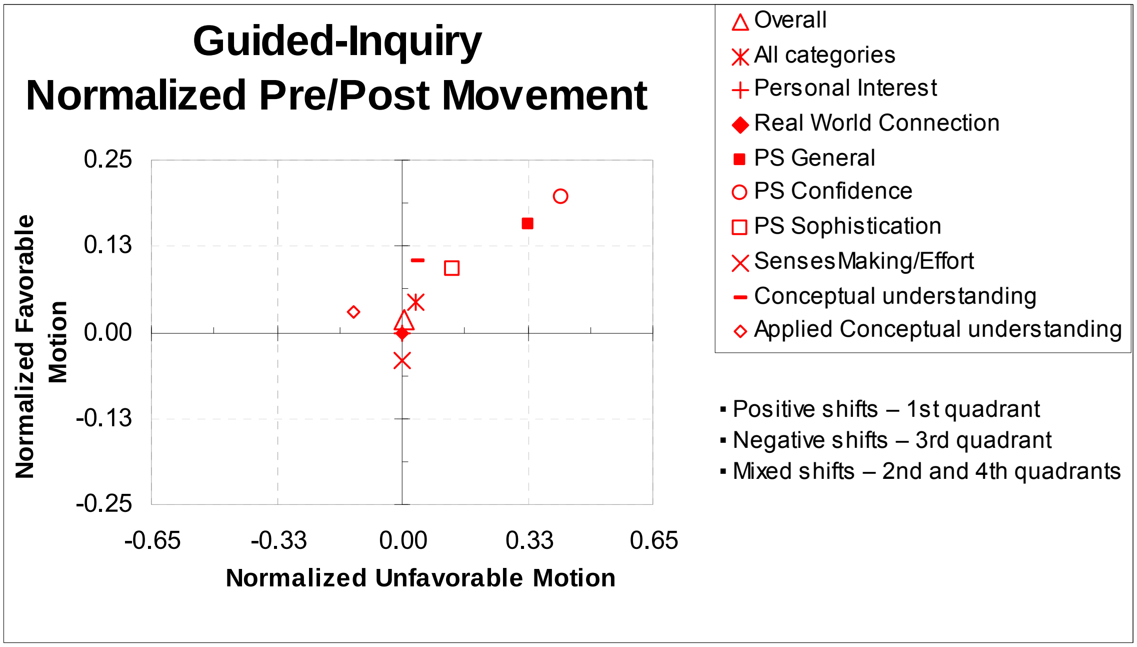

Figure 4-12: Shifts in Opinions of Guided-inquiry Students by Subcategory

The overall movement of all questions appeared to be more positive for the guided-inquiry class. These students responded particularly positively on the three categories addressing “Problem Solving” (Figure 4-12). For the open-inquiry students, positive shifts were strongest in questions addressing “Real World Connections” and “Personal Interest” (Figure 4-11).

The researcher was interested in how large a factor these positive categories played in the overall survey scores as they seemed to reflect the different focuses of each of the teaching approaches. The guided-inquiry class spent much more time solving problems than on laboratory activities; the additional lab time in the open-inquiry class was specifically concerned with real life applications of concepts.

Normalized overall shifts in opinion were recalculated excluding the questions that played to the strengths of each class (Figure 4-13). When the “Problem Solving” questions (a total of 11) were removed from the analysis, open-inquiry responses were affected little, but guided-inquiry responses were sharply more negative. Removing “Real World Connection” and “Personal Interest” questions (a total of 8) reveals a negative shift in unfavorable answers for the open-inquiry class, while favorable opinions remain mostly unchanged. The guided-inquiry responses show somewhat the inverse: constant unfavorable opinions with a positive shift in favorable opinions. Each approach appeared to have a positive effect on the opinions of students in the areas of focus for each course.

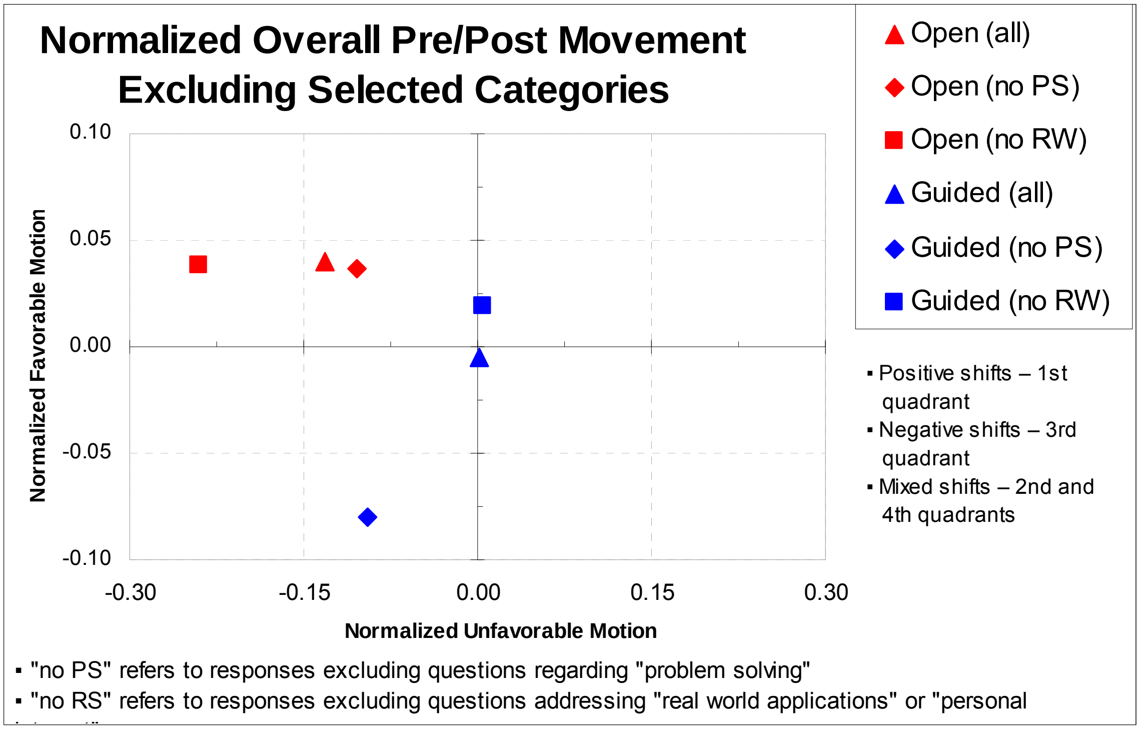

Figure 4-13: Normalized Shifts in CLASS Responses Excluding Selected Categories

5 Conclusions

A Comparison of two different student-centered approaches was needed to further the understanding of the effect of different levels of inquiry on student learning and attitudes. Five science teachers were surveyed and the classes were given average ratings of 2.9 and 4.4 (a difference of 1.5) for the guided and open-inquiry approaches on the science inquiry matrix (Table 1-1). Students in both treatments were drawn from the same population and were taught by the same instructor. The methods employed were distinguished as guided-inquiry (MIP) and open-inquiry (Roth), where the primary difference was the time spent solving computational problems being replaced with lab investigations that originated with the students. Though time spent on each topic for the two treatments was not identical, the ordering of content was the same and the pacing was relatively similar.

5.1 Conclusions Relevant to Research Question 1

The first question was to investigate potential statistically and practically significant differences in the short-term and long-term scored responses of students in one type of open and guided-inquiry high school physics classrooms. The guided-inquiry approach followed the “Modeling Instruction Program” developed at Arizona State

University, while the open-inquiry approach was modeled after the work of Wolff-Michael Roth, at Simon Fraser University.

As measured by the first FCI posttest, in the short term there were no differences of statistical significance and only small practical significance in the larger gain scores of the guided-inquiry classes. The second FCI posttest showed that there was neither practical nor statistical significance in the difference of long-term scores. Viewing these pre-post test results independently, one finds that pre to post test gain scores for each class individually had statistical and high practical significance. The normalized gain scores of .40 and .38 for the open and guided inquiry courses respectively both fell in the "medium gain" range of scores on the FCI as defined by Hake (1998) in his analysis of 14 high school classes (involving 1113 students), none of which were classified as "high gain." Considering these data, the researcher concluded that a high school physics teacher could achieve satisfactory results with either inquiry approach.

A curious result arises when one compares the scores on each of the FCI posttests which were administered between 10 and 11 weeks apart with no additional instruction on forces or motion in the interim. Both treatments not only continued to increase their scores (Figure 5-1, Figure 5-2, and Figure 5-3), but the mean scores of the open-inquiry classes actually surpassed the scores for the guided-inquiry class despite having scored lower on the first posttest. Comparing the gain scores of the two approaches between posttests showed a difference between the increases that was statistically significant and at the high end of the medium range of practical significance.

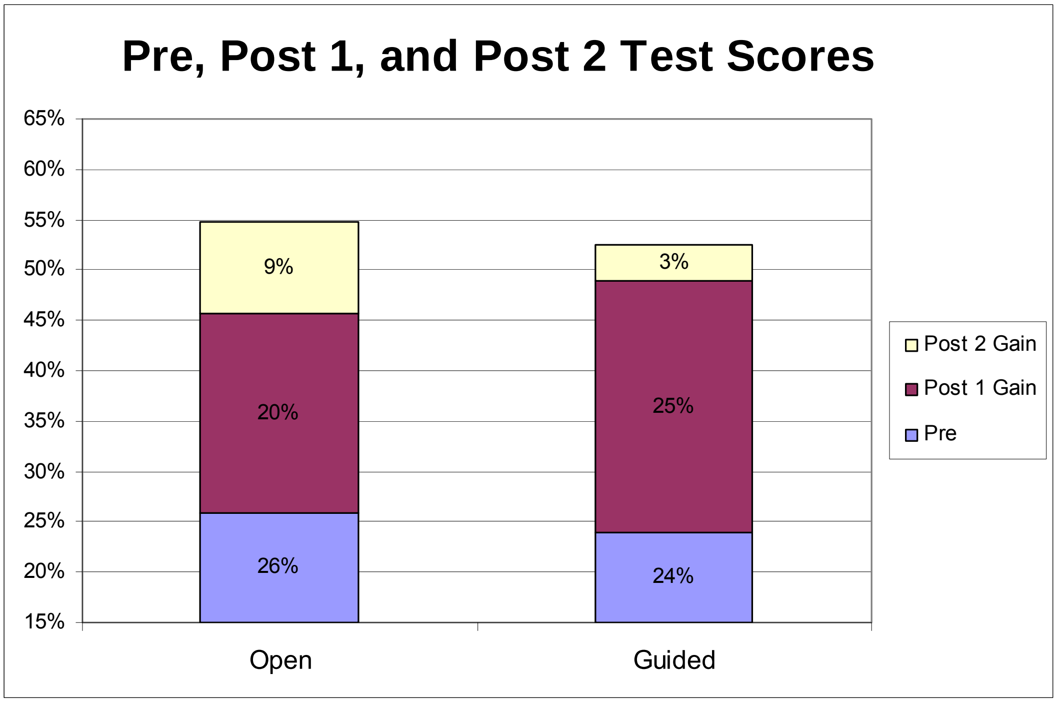

Figure 5-1: FCI Mean Scores

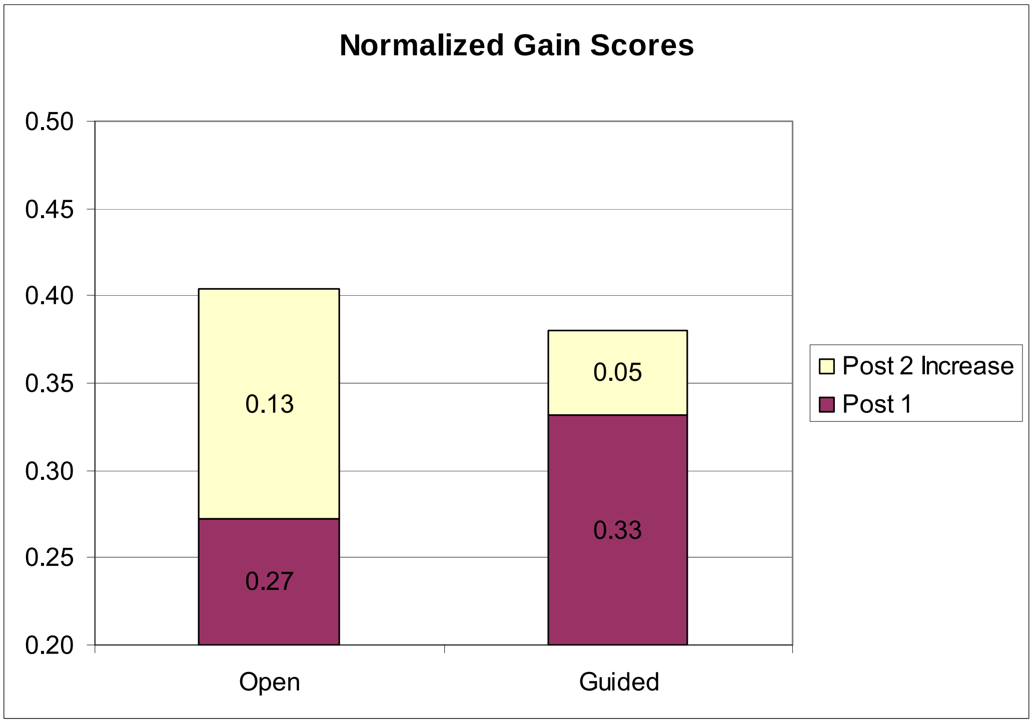

Figure 5-2: FCI <g> Scores

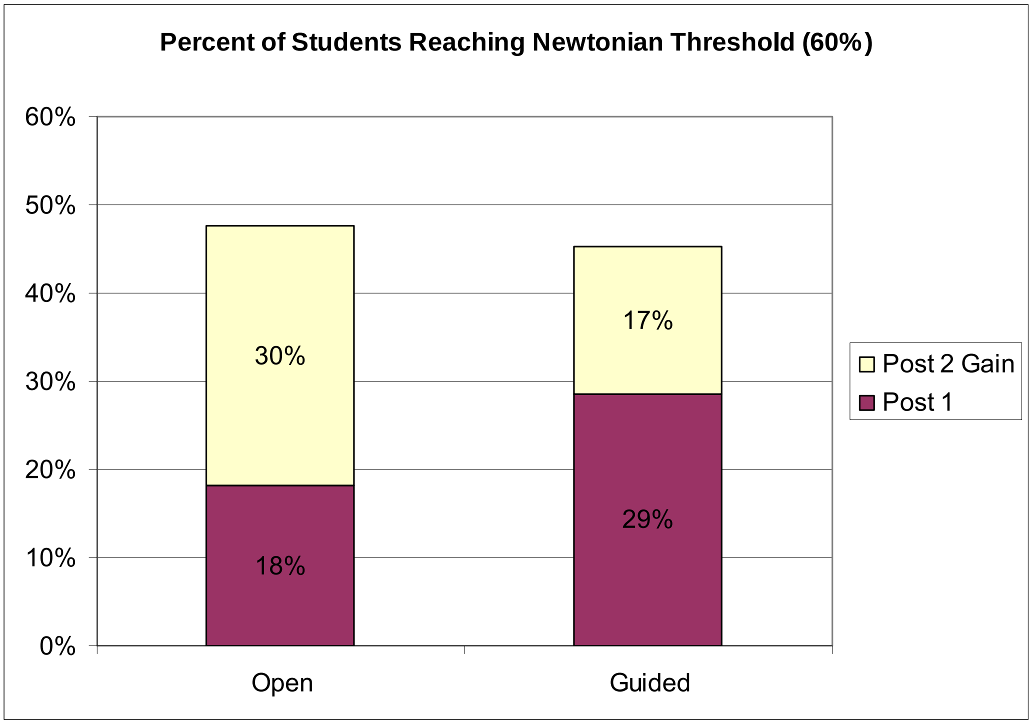

Figure 5-3: Student Achieving Newtonian Thinking as Measured by the FCI

The increased scores of both treatments is likely explained by the fact that the students had a chance to review the content on the FCI before posttest 2 and not before posttest 1. Additionally, while the content on the FCI was not studied explicitly between the two posttests, some of the concepts were incorporated in the study of later material. Yet neither of these explanations addresses the fact that the increase in scores was significantly greater for the open-inquiry group. This could possibly be the result of a more structured review experience tying together ideas that had previously remained somewhat nebular for the open-inquiry students. Also, the instructor did notice a greater decrease in focus and motivation for the guided-inquiry students as the end of the school year approached.

The CRT (state core) gave a confirmation of the effectiveness of the two inquiry approaches. Mean percentage scores of 74% and 68% for the open and guided-inquiry classes were both above the 2007 state and district averages of 63% and 65%, though comparison should remain cursory as these averages include a much more varied student population as well as teachers employing a range of methodologies. In comparing the guided and open-inquiry treatments, the CRT served as a secondary measure of short-term learning and indicated a greater mean score for the open-inquiry students that was barely statistically significant and of medium practical significance. While encouraging to the researcher, the CRT findings taken with the null result of the more robust FCI exam made it difficult to conclude that one treatment had a more positive effect on scored responses addressing student understanding of physics concepts.

5.2 Conclusions Relevant to Research Question 2

The second question addressed differences in survey responses regarding student attitudes towards physics. Both treatments were found to have somewhat unfavorable effects on students' opinions: the open-inquiry class increased both in responses agreeing and disagreeing with the expert opinion, with a greater increase in responses opposite of the expert. The guided-inquiry class decreased both in responses agreeing and disagreeing with the expert opinion, with a greater decrease for responses in agreement with the expert. Additionally, the increases in agreement and disagreement of the open-inquiry students were greater than the decreases of the guided-inquiry students, indicating that the open-inquiry treatment had a more polarizing effect on the attitudes of students towards physics. From these results one may conclude that the open-inquiry class required the students to confront physics in such a way as to lead to stronger opinions being formed than those of the guided-inquiry students.

Opinions on sub-categories did appear to be influenced by the specific focus of each class. When removing questions regarding “problem solving” from the guided-inquiry responses, large shifts in decreased agreement and increased disagreement were observed. This means that most positive opinions that the guided-inquiry students had towards physics were related to their confidence in their problem solving abilities. Similarly, when questions addressing “real world connections” and “personal interest” were removed from the analysis of open-inquiry responses, a large increase in disagreement with the expert was found. This would indicate that the progress in opinions towards physics made by the open-inquiry students dealt with relating physics to themselves and seeing physics in the world around them. It was thus difficult to conclude that one treatment had a more positive overall influence on students’ attitudes towards physics, but it was clear that the differing approaches affected opinions in distinct ways.

5.3 Comparing with Previous Research

The researcher came to similar conclusions as Faulkner (1992) concerning the learning of students exposed to differing levels of inquiry. Both studies found the varying levels to be equally effective. The current study did diverge with Faulkner in its findings relating to changes in student opinions following the treatments. Faulkner (1992) reported no difference in attitudes whereas the researcher found that students in an open-inquiry classroom were pushed away from neutral opinions while those in the guided-inquiry treatment were pushed towards them.

5.4 Observations

While finding little of measurable significance in this study, the experience was a significant one for the instructor and the students participating in the study. When, comparing the significant time in desks working problems during the guided-inquiry class with the chaos that often accompanied the planning of a new lab investigation in the open-inquiry treatment, the researcher was surprised that each class ended up at nearly the same place academically and that both classes were relatively successful. This result gave the instructor the freedom to choose a greater diversity of instructional methods with confidence in their effectiveness. The researcher felt that this was of critical importance in helping instructors renew their enthusiasm for teaching and avoid stagnation in a single methodology.

After the experience, the researcher also felt that the question when comparing student-centered approaches was not so much about how much structure a classroom had, but more about where the structure was placed in the learning process. Students need to be given some degree of direction as they are highly unlikely to spontaneously uncover Newton's laws of motion. The choice appears to be to let them initially wander a bit and then formalize and apply their experience, or to teach them new concepts rather directly followed by giving them the freedom to investigate applications.

5.5 Internal Validity Issues

To increase the validity of this study, a number of variables could have been controlled more effectively. The fact that the teacher involved was also acting as the researcher necessarily introduces additional biases into the administration of the treatments as well as the conclusions drawn from the findings. Another difficulty with the instructor was that he had prior familiarity with the guided-inquiry approach but absolutely no experience teaching with open-inquiry.

The slight pacing differences of the two treatments meant that both groups did not spend exactly equal amounts of time on each physics concept. Additionally, there were a few students who switched from one class to the other and most students were generally aware that the instructor was employing two different teaching approaches. While data included only students isolated to one treatment for the entire year, diffusion effects were possible as the students were located in the same school and likely interacted with members of the other treatment outside of class.

5.6 Recommendations

While both student-centered approaches were found to adequately teach introductory physics concepts to high school students in these four classes, the high school in which this study was conducted serviced an area of high-socioeconomic status where students generally have a great degree of academic support and motivation. Similar research in other populations (minority, lower-income, or non-college bound students) is needed. A population with less academic support might react to the varying levels of student responsibility completely differently than the students involved in this study.

It was observed in the open-inquiry classroom of the current study, as in that conducted by Roth, that considerable time was needed for the students to acclimatize to the redistribution of responsibilities in the classroom. For this reason, it is suggested that future studies avoid comparison of inquiry levels taught over the short-term. Time must be given for the students to become enculturated when they are introduced into a new environment.

Other research might focus more precisely on the qualifications of the teacher. The physics instructor administering the treatments in this study had no formal training in either teaching approach. He did have two years experience employing guided-inquiry methods while having virtually no experience working in an open-inquiry classroom. Perhaps having a traditional teacher who is not experienced in either approach attempt a similar experiment would yield more valid results.

The researcher also feels that effective classroom practice is largely dependent on the subject being taught and the individualities of the teacher (in addition to the student population). Investigation of differing levels of inquiry in other disciples or within physics with numerous instructors administering the treatments would continue to probe the outcomes of student-centered approaches.

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APPENDICES

Appendix A. MIP Lab Sample

Modified Atwood's machine lab

Apparatus

wheeled carts dynamics carts glider
wood ramps PASCO tracks airtracks
pulleys with clamps
balance for mass measurement
hangers for slotted weights (or equivalent)
spring scales (newton calibration)
photogates
ULI Timer, Logger Pro, or Data Studio software
Graphical Analysis

Pre-lab discussion

- Allow a suspended mass to tow a cart (glider) across the track; ask students to observe its motion. We've already established that a force is required to produce an acceleration. We just haven't quantified the relationship. Rather than brainstorming general observations, ask them to identify other factors that might affect the acceleration of the cart. To proceed, the list must include mass, amount of friction, and amount of force used to tow cart.
- Ask them for ideas on how to minimize the effect of friction. After some discussion, they will hopefully come to the idea of inclining the ramp slightly to compensate for friction.
- Ask them how to measure the acceleration of the cart. While they cannot measure it directly, there are at least two ways to do determine the acceleration. One can calculate it from rearrangement of the kinematical model $\Delta x = \frac{1}{2}at^2$. (Note: The use of this model requires the assumption that acceleration is constant. The rationale for such an assumption could be based on an "extra credit" lab.) Another method is to allow a picket fence affixed to the cart to pass through a photogate. The slope of the velocity vs time graph yields the acceleration.
- The dependent variable is the acceleration of the cart.
- The independent variables are the mass of the cart/hanger system and the force used to pull the cart.

- Make sure to stress that the mass that is being accelerated is the total mass of the system (the cart and hanging mass are connected, so must accelerate at the same rate).

Lab performance notes

- Use small mass hangers (e.g. 5g) and change by 10 to 20g increments.
- Increase cart mass by 0.2 - 0.5 kg increments.
- Adjust the angle of incline so that the cart can move at a constant speed with a very small initial push.
- Convince students that they must transfer mass from the cart to the hanger in order to keep the total mass constant when they vary the force.
- Convert the hanging mass to newtons.
- See sample graphs in Figures 1, 2, and 3.

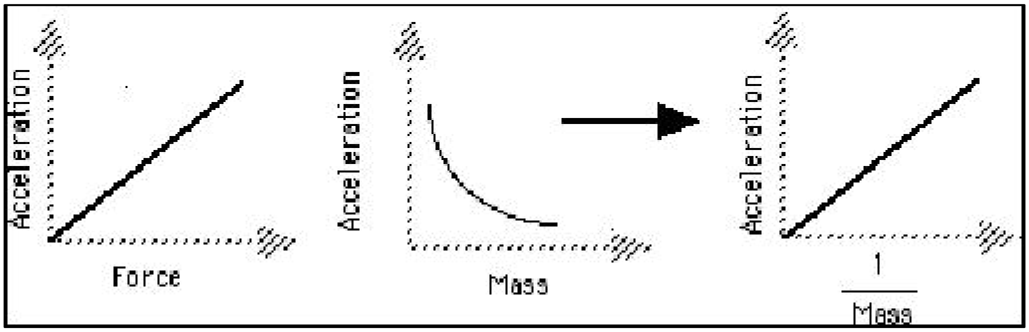


Figure 1 Figure 2 Figure 3

Post-lab discussion

- Since the units of slope are not intuitive, focus on proportionalities.
- Discuss the combination of two proportionalities into one:

$$a \propto F_{net} \qquad a \propto \frac{1}{m} \quad \Rightarrow \quad a \propto \frac{F_{net}}{m}$$

- Turn the proportionality into an equation; rearrange to solve for k.

$$a = k\frac{F_{net}}{m} \Rightarrow k = \frac{ma}{F_{net}}$$

- Substitute values from regression line to solve for k. With luck, students' values should cluster around 1.0. Now is the time to point out that the slope of force of gravity vs mass (9.8 N/kg) and the slope of velocity vs time (9.8 m/s^2) have the same numerical value due to the way the newton was defined.

Appendix B. MIP Lab Report Instructions

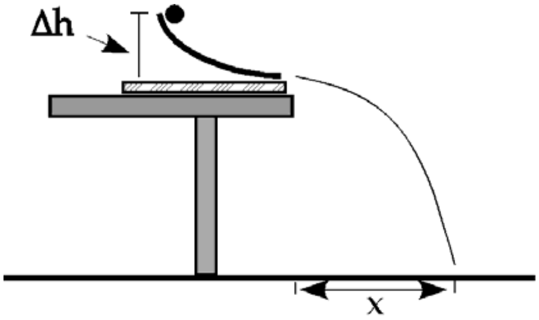
Writing the Physics Lab Report

Labs are the basis for our understanding of the key concepts in physics. What follows are the guidelines for success in writing a quality lab report.

1. You should keep all data collected during the lab on loose leaf paper in the physics section of the Study Skills binder.
2. All laboratory reports are to be written *in pen* on loose leaf paper or word-processed. *You should write on one side only.*
3. Your name, the name(s) of all members of your laboratory team and the date the investigation was performed is to be written in the upper right hand corner of the first page of each report.
4. An appropriate title for the report should be placed in the center of the first page of the report.
5. Each of the following sections of the laboratory report should be prefaced with the section names.

Purpose This is a statement of the problem to be investigated. It provides the overall direction for laboratory investigation and must be addressed in the conclusion.

Apparatus All laboratory apparatus used in the investigation, along with a detailed diagram to illustrate the configuration of the apparatus, should be included in this section. See example at right. The variables to be measured should be clearly pictured.



Procedure This section should identify and name all experimental variables and briefly describe how the independent variables are controlled. Someone who was not present during the lab should be able to understand how the experiment was performed by reading your procedure.

Data

Data consists only of those values measured directly from the experimental apparatus.

No values obtained by way of mathematical manipulations or interpretations of any kind may be included in this section of the report. Data should consist of as many trials as judgement would indicate necessary. The units for physical measurements (kg, m, s, etc.) in a data table should be specified in column heading only.

Evaluation of Data

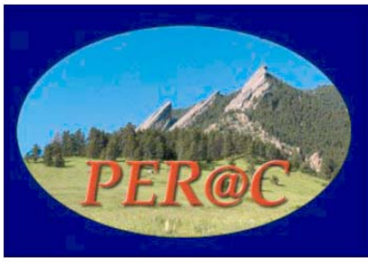
This section should include all graphs, analysis of graphs, and post laboratory calculations. State each formula, and if necessary, identify the symbols used in the formula. If repetitive calculations are to be performed, substitute *only one set of data* into each formula and then construct a **table of values** for all additional calculated values. Be certain that your final calculated values are expressed to the correct number of significant figures. Do not show your arithmetic calculations.

Conclusion

In the conclusion you must do the following:

a) State the relationship between the variables identified in the purpose in a clear, concise English sentence.
b) When a mathematical expression can be derived from graphical analysis, write it, making sure to include the appropriate units. State the *meaning of the slope* and discuss the *significance of the y-intercept* (when appropriate).
c) Describe any new terms that arise as a result of your evaluation of data.
d) When your results differ from what is expected, provide a plausible explanation.

Appendix C. CLASS



CLASS

(Colorado Learning Attitudes about Science Survey)

Name: ___________________________________ **Last 6 digits of your Student ID #:** _______

Introduction

Here are a number of statements that may or may not describe your beliefs about learning physics. 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

Choose one of the above five choices that best expresses your feeling about the statement. If you don't understand a statement, leave it blank. If you understand, but have no strong opinion, choose 3.

Survey

1. A significant problem in learning physics is being able to memorize all the information I need to know.

Strongly Disagree	1 2 3 4 5	Strongly Agree

2. When I am solving a physics problem, I try to decide what would be a reasonable value for the answer.

Strongly Disagree	1 2 3 4 5	Strongly Agree

3. I think about the physics I experience in everyday life.

Strongly Disagree	1 2 3 4 5	Strongly Agree

4. It is useful for me to do lots and lots of problems when learning physics.

Strongly Disagree	1 2 3 4 5	Strongly Agree

5. After I study a topic in physics and feel that I understand it, I have difficulty solving problems on the same topic.

Strongly Disagree	1 2 3 4 5	Strongly Agree

6. Knowledge in physics consists of many disconnected topics.

Strongly Disagree	1 2 3 4 5	Strongly Agree

7. As physicists learn more, most physics ideas we use today are likely to be proven wrong.

Strongly Disagree	1 2 3 4 5	Strongly Agree

8. When I solve a physics problem, I locate an equation that uses the variables given in the problem and plug in the values.

Strongly Disagree	1 2 3 4 5	Strongly Agree

9. I find that reading the text in detail is a good way for me to learn physics.

Strongly Disagree	1 2 3 4 5	Strongly Agree

10. There is usually only one correct approach to solving a physics problem.

Strongly Disagree	1 2 3 4 5	Strongly Agree

11. I am not satisfied until I understand why something works the way it does.

Strongly Disagree	1 2 3 4 5	Strongly Agree

12. I cannot learn physics if the teacher does not explain things well in class.

Strongly Disagree	1 2 3 4 5	Strongly Agree

13. I do not expect physics equations to help my understanding of the ideas; they are just for doing calculations.

Strongly Disagree	1 2 3 4 5	Strongly Agree

14. I study physics to learn knowledge that will be useful in my life outside of school.

Strongly Disagree	1 2 3 4 5	Strongly Agree

15. If I get stuck on a physics problem my first try, I usually try to figure out a different way that works.

Strongly Disagree	1 2 3 4 5	Strongly Agree

16. Nearly everyone is capable of understanding physics if they work at it.

Strongly Disagree	1 2 3 4 5	Strongly Agree

17. Understanding physics basically means being able to recall something you've read or been shown.

Strongly Disagree	1 2 3 4 5	Strongly Agree

18. There could be two different correct values to a physics problem if I use two different approaches.

Strongly Disagree	1 2 3 4 5	Strongly Agree

19. To understand physics I discuss it with friends and other students.

Strongly Disagree	1 2 3 4 5	Strongly Agree

20. I do not spend more than five minutes stuck on a physics problem before giving up or seeking help from someone else.

Strongly Disagree	1 2 3 4 5	Strongly Agree

21. If I don't remember a particular equation needed to solve a problem on an exam, there's nothing much I can do (legally!) to come up with it.

Strongly Disagree	1 2 3 4 5	Strongly Agree

22. If I want to apply a method used for solving one physics problem to another problem, the problems must involve very similar situations.

Strongly Disagree	1 2 3 4 5	Strongly Agree

23. In doing a physics problem, if my calculation gives a result very different from what I'd expect, I'd trust the calculation rather than going back through the problem.

Strongly Disagree	1 2 3 4 5	Strongly Agree

24. In physics, it is important for me to make sense out of formulas before I can use them correctly.

Strongly Disagree	1 2 3 4 5	Strongly Agree

25. I enjoy solving physics problems.

Strongly Disagree	1 2 3 4 5	Strongly Agree

26. In physics, mathematical formulas express meaningful relationships among measurable quantities.

Strongly Disagree	1 2 3 4 5	Strongly Agree

27. It is important for the government to approve new scientific ideas before they can be widely accepted.

Strongly Disagree	1 2 3 4 5	Strongly Agree

28. Learning physics changes my ideas about how the world works.

Strongly Disagree	1 2 3 4 5	Strongly Agree

29. To learn physics, I only need to memorize solutions to sample problems.

Strongly Disagree	1 2 3 4 5	Strongly Agree

30. Reasoning skills used to understand physics can be helpful to me in my everyday life.

Strongly Disagree	1 2 3 4 5	Strongly Agree

31. We use this statement to discard the survey of people who are not reading the questions. Please select agree-option 4 (not strongly agree) for this question to preserve your answers.

Strongly Disagree	1 2 3 4 5	Strongly Agree

32. Spending a lot of time understanding where formulas come from is a waste of time.

Strongly Disagree	1 2 3 4 5	Strongly Agree

33. I find carefully analyzing only a few problems in detail is a good way for me to learn physics.

Strongly Disagree	1 2 3 4 5	Strongly Agree

34. I can usually figure out a way to solve physics problems.

Strongly Disagree	1 2 3 4 5	Strongly Agree

35. The subject of physics has little relation to what I experience in the real world.

Strongly Disagree	1 2 3 4 5	Strongly Agree

36. There are times I solve a physics problem more than one way to help my understanding.

Strongly Disagree	1 2 3 4 5	Strongly Agree

37. To understand physics, I sometimes think about my personal experiences and relate them to the topic being analyzed.

Strongly Disagree	1 2 3 4 5	Strongly Agree

38. It is possible to explain physics ideas without mathematical formulas.

Strongly Disagree	1 2 3 4 5	Strongly Agree

39. When I solve a physics problem, I explicitly think about which physics ideas apply to the problem.

Strongly Disagree	1 2 3 4 5	Strongly Agree

40. If I get stuck on a physics problem, there is no chance I'll figure it out on my own.

Strongly Disagree	1 2 3 4 5	Strongly Agree

41. It is possible for physicists to carefully perform the same experiment and get two very different results that are both correct.

Strongly Disagree	1 2 3 4 5	Strongly Agree

42. When studying physics, I relate the important information to what I already know rather than just memorizing it the way it is presented.

Strongly Disagree	1 2 3 4 5	Strongly Agree

Appendix D. CLASS Expert Responses

Question	Expert Opinion
1. A significant problem in learning physics is being able to memorize all the information I need to know.	Disagree
2. When I am solving a physics problem, I try to decide what would be a reasonable value for the answer.	Agree
3. I think about the physics I experience in everyday life.	Agree
4. It is useful for me to do lots and lots of problems when learning physics.	N/A
5. After I study a topic in physics and feel that I understand it, I have difficulty solving problems on the same topic.	Disagree
6. Knowledge in physics consists of many disconnected topics.	Disagree
7. As physicists learn more, most physics ideas we use today are likely to be proven wrong.	N/A
8. When I solve a physics problem, I locate an equation that uses the variables given in the problem and plug in the values.	Disagree
9. I find that reading the text in detail is a good way for me to learn physics.	N/A
10. There is usually only one correct approach to solving a physics problem.	Disagree
11. I am not satisfied until I understand why something works the way it does.	Agree
12. I cannot learn physics if the teacher does not explain things well in class.	Disagree
13. I do not expect physics equations to help my understanding of the ideas; they are just for doing calculations.	Disagree
14. I study physics to learn knowledge that will be useful in my life outside of school.	Agree
15. If I get stuck on a physics problem on my first try, I usually try to figure out a different way that works.	Agree
16. Nearly everyone is capable of understanding physics if they work at it.	Agree
17. Understanding physics basically means being able to recall something you've read or been shown.	Disagree
18. There could be two different correct values for the answer to a physics problem if I use two different approaches.	Disagree
19. To understand physics I discuss it with friends and other students.	Agree
20. I do not spend more than five minutes stuck on a physics problem before giving up or seeking help from someone else.	Disagree

21. If I don't remember a particular equation needed to solve a problem on an exam, there's nothing much I can do (legally!) to come up with it.	Disagree
22. If I want to apply a method used for solving one physics problem to another problem, the problems must involve very similar situations.	Disagree
23. In doing a physics problem, if my calculation gives a result very different from what I'd expect, I'd trust the calculation rather than going back through the problem.	Disagree
24. In physics, it is important for me to make sense out of formulas before I can use them correctly.	Agree
25. I enjoy solving physics problems.	Agree
26. In physics, mathematical formulas express meaningful relationships among measurable quantities.	Agree
27. It is important for the government to approve new scientific ideas before they can be widely accepted.	Disagree
28. Learning physics changes my ideas about how the world works.	Agree
29. To learn physics, I only need to memorize solutions to sample problems.	Disagree
30. Reasoning skills used to understand physics can be helpful to me in my everyday life.	Agree
31. We use this statement to discard the survey of people who are not reading the questions. Please select agree (not strongly agree) for this question to preserve your answers.	N/A
32. Spending a lot of time understanding where formulas come from is a waste of time.	Disagree
33. I find carefully analyzing only a few problems in detail is a good way for me to learn physics.	N/A
34. I can usually figure out a way to solve physics problems.	Agree
35. The subject of physics has little relation to what I experience in the real world.	Disagree
36. There are times I solve a physics problem more than one way to help my understanding.	Agree
37. To understand physics, I sometimes think about my personal experiences and relate them to the topic being analyzed.	Agree
38. It is possible to explain physics ideas without mathematical formulas.	Agree
39. When I solve a physics problem, I explicitly think about which physics ideas apply to the problem.	Agree
40. If I get stuck on a physics problem, there is no chance I'll figure it out on my own.	Disagree
41. It is possible for physicists to carefully perform the same experiment and get two very different results that are both correct.	N/A
42. When studying physics, I relate the important information to what I already know rather than just memorizing it the way it is presented.	Agree

Appendix E. CLASS Sub-Categories

PERSONAL INTEREST	DO STUDENTS FEEL A PERSONAL INTEREST IN /CONNECTION TO PHYSICS (Q's: 3, 11, 14, 25, 28, 30)
REAL WORLD CONNECTION	SEEING THE CONNECTION BETWEEN PHYSICS AND REAL LIFE (Q's: 28,30,35,37)
PROBLEM SOLVING GENERAL	(Q's: 13,15,16,25,26,34,40,42)
PROBLEM SOLVING CONFIDENCE	(Q's: 15,16,34,40)
PROBLEM SOLVING SOPHISTOCATION	(Q's: 5,21,22,25,34,40)
SENSEMAKING/EFFORT	FOR ME (THE STUDENT) EXERTING THE EFFORT NEEDED TOWARDS SENSE-MAKING IS WORTHWHILE (Q's: 11,23,24,32,36,39,42)
CONCEPTUAL UNDERSTANDING	UNDERSTANDING THAT PHYSICS IS COHERENT AND IS ABOUT MAKING-SENSE, DRAWING CONNECTIONS, AND REASONING NOT MEMORIZING. MAKING SENSE OF MATH (Q's: 1,5,6,13,21,32)
APPLIED CONCEPTUAL UNDERSTANDING	UNDERSTANDING AND APPLYING A CONCEPTUAL APPROACH AND REASONING IN PROBLEM SOLVING, NOT MEMORIZING OR FOLLOWING PROBLEM SOLVING RECIPES (Q's: 1,5,6,8,21,22,40)

Appendix F. Physics Final Review

I. General Motion
  a. Position – your location
  b. Distance – how far you have gone
  c. Displacement – how far you have gone and in what direction
  d. Speed – how fast your location is changing
  e. Velocity – how fast your location is changing and in what direction
  f. Acceleration – how fast your velocity is changing
    i. There is acceleration when you
      1. speed up
      2. slow down
      3. change direction

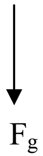
II. Newton's Laws of Motion
  a. 1st – An object in motion will remain in motion (or an object at rest will remain at rest) unless acted on by a net force
    i. If forces are balanced ($F_{net}=0$), the motion of an object does not change. It will be either:
      1. at rest (not moving)
      2. moving, but at a constant speed
  b. 2nd
    i. If forces are unbalanced ($F_{net}\neq 0$), the object will accelerate (speed up or slow down)
      1. How much it accelerates depends on the mass of the object and the strength of the force ($F=ma$)
  c. 3rd – For every action there is an equal and opposite reaction
    i. All forces are an interaction between two objects. Each object pushes or pulls on the other with the same amount of force, but in the opposite direction

III. Identifying Forces
    i. Any objects that are touching will exert forces on each other
    ii. A few forces can act without objects touching (gravity, electromagnetic forces)
    iii. Mass vs. Weight
      1. Mass is how much stuff (matter) there is, it does not change (you have the same mass on the moon)

        2. Weight is how much gravity is pulling on your mass (F_g), it does change if you leave Earth (you weigh less on the moon)
    iv. Net Force (F_{net}) - what is left over after subtracting forces in opposite directions
    v. Friction
        1. Two types:
            a. static friction – keeps objects that are not moving from starting to move (eg – a car parked on a hill)
                i. can vary depending on the force trying to move the object
            b. kinetic friction – slows down moving objects, always pushes in the direction opposite of motion
                i. is constant for given surfaces, doesn't change with increased speed
        2. The strength of both types are determined by the types of surfaces involved (given by μ) and how hard the surfaces are pushing on each other (given by F_N)

IV. Circular Motion
    a. All objects travelling in a circle are accelerating because their direction is changing
        i. The direction of the acceleration is always towards the center of the circle
    b. All objects travelling in a circle have a F_{net} acting towards the center of the circle
        i. This force pushing/pulling towards the center is known as the centripetal force
        ii. If the centripetal force is removed, the object will immediately travel in a straight line

V. Projectiles
    a. When an object is moving in 2 dimensions, you can treat each dimension completely separately
    b. With negligible (so small it can be ignored) air resistance, a projectile has no forces acting on it in the horizontal (X) direction, and only gravity acting on it in the vertical (Y) direction
    c. The force diagram for every projectile is:



    d. Every projectile has constant velocity (no acceleration) in the horizontal direction and constant acceleration (due to gravity) in the vertical direction
    e. All projectiles follow parabolic paths
    f. All projectiles fall at the same rate, regardless of mass or horizontal velocity