INTERACTIVE ENGAGEMENT IN AN INTRODUCTORY UNIVERSITY PHYSICS COURSE: LEARNING GAINS AND PERCEPTIONS

by

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ABSTRACT

At Kansas State University we have altered our calculus-based introductory physics course to create the *New Studio* format for teaching fundamental physics to large undergraduate classes. This format retains the large lecture component but combines recitation and laboratory instruction into the *New Studio*. Studio is composed of 40 students working in groups of four at tables equipped with modern instructional technology and other apparatus. The group setting allows for peer instruction and development of group skills. Each sequence of the course begins with a traditional lecture to economically introduce students to new ideas, with an emphasis on physics concepts, followed the next day by Studio, an integration of simple experiments/demonstrations with corresponding problems from the previous night's homework set. This sequence occurs twice each week. In this way, problem solving and analysis activities are built into the context of the real, hands-on demonstrations.

The purpose of this study was to ascertain the perceptions of the students and instructors concerning the change from the traditional format to an interactive-engagement format as well as to determine the conceptual gains that the students may have made. To address these questions, open-ended and Lickert scale question surveys were developed and administered to all students enrolled in the courses in the new format. In addition, students volunteered to be interviewed, on an individual basis, throughout the semester, and all instructors involved in the teaching of the courses were interviewed. Finally, conceptual surveys were administered, pre- and post-instruction to evaluate learning gains.

The results of this study show that the students find the interactive-engagement method of learning physics to be a positive experience. They liked the integration of homework and laboratory activities, working in groups, and having the opportunity to interact, individually, with instructors. The instructors also considered the new format to be a positive change for similar reasons. The comparison of the pre- and post-instruction surveys indicated that the students made significant conceptual gains in the new format. In light of these results, it is evident that Studio has made a positive impact on the introductory, calculus-based physics course at Kansas State University.

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AKNOLWEDGMENTS

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Chapter One: Introduction

Those of us who have been teaching physics over the years have come to realize that our students are not learning what we think we are teaching them. They leave our classrooms with gaps in their understanding of basic physics concepts. What can we do about this problem? Within the past thirty years, physicists have begun to use a scientific approach to address this issue. We are systematically researching how students learn physics and how we teach physics (McDermott & Redish, 1999). Using the results of this research, we, the physics education research community, are developing curriculum materials and teaching formats which are better suited for our audience – the student. These materials include activities which require the student to be actively involved in their learning. Instead of sitting still, listening and watching the instructor, students are interacting with each other and the instructor as well as performing hands-on experiments. At Kansas State University, we are no different. In the past, we have taught our introductory, calculus-based physics course in the traditional, lecture/recitation/laboratory format with unsatisfactory results. Consequently, we have developed a new format for teaching our course.

1.1 *New Studio at Kansas State University*

Beginning the Fall semester of 1994, the Physics Department at Kansas State University (K-State) collected student evaluations of the courses taught using a teaching evaluation tool, TEVAL, developed by the Planning and Evaluation Services of the Office of Educational Improvement at K-State. The results of these evaluations showed that students were dissatisfied with the course format – lecture/laboratory/recitation. They gave low ratings to the compatibility of the laboratory with the lecture. However, they did prefer the smaller class sizes of the laboratory and recitation and the resulting increased student-instructor interaction. In addition to surveys, qualitative data from individual interviews with students, faculty and laboratory instructors indicated that students had difficulty making conceptual connections between the homework and laboratory experiments. As these results were in accord with those at similar institutions nation wide, an ad hoc department committee met during the 1997-1998 academic year to determine how to improve the physics instruction at K-State. The committee developed four goals. These goals were to

1. Improve the conceptual understanding of physical concepts for students who frequently focus on mathematical problem solving of physics and the number crunching in the laboratory.
2. Decrease the time which students spend capturing and manipulating data coupled with an increase in the time spent in analysis of the data and related concepts.
3. Increase the time available for meaningful inquiry and discovery activities.
4. Increase the amount of professor-student and student peer instruction. (Sorensen & Maleki, 1998)

To attain these goals, the committee decided that it would be necessary to change from the traditional lecture/laboratory/recitation format to an interactive, hands-on approach similar to those at some other large, research universities. The committee proposed to develop a format they called “New Studio” based on the Studio Physics format developed at Rensselaer Polytechnic Institute for the calculus-based introductory physics course – Engineering Physics (Sorensen & Maleki, 1998).

In the past, the lecture served approximately 150 students, met for one hour twice a week, and was taught by a faculty member. The lecture class was divided into recitation groups of 40 students - which met for one hour twice a week - and laboratory groups of 30 students - which met once a week for two hours. The recitations were taught by faculty members and the laboratories by graduate students or upper level undergraduates. The New Studio format retains the lecture from the traditional format, but combines the recitation and laboratory into a single classroom environment or Studio. Studio serves 40 students in a section, meets for two hours twice a week, and is co-taught by a faculty member and a graduate student or upper level undergraduate. The lecture aspect of the course was kept for several reasons. First, the lecture does work for some students' learning style. By keeping the lecture, we are not detracting from those students' learning experience. Second, while some classroom modification is necessary, major building renovations are not necessary. Finally, it is economically feasible. While in the ideal world, all classes would be small with frequent interaction between students and instructors, the Physics Department at K-State does not have the resources or space to completely abandon the lecture.

After applying for and receiving a Course, Curriculum, and Laboratory Improvement (CCLI) grant from the National Science Foundation (NSF) a Development Team was created as an off-shoot from the department committee. The core members of the Development Team were Chris Sorensen, a faculty member and principle investigator on the NSF grant, Suzanne Maleki, the Director of Undergraduate Laboratories and co-investigator, Peter Nelson, the Physics Instructional Resource Specialist, Amit Chakrabarti, a faculty member and this researcher. When Suzanne Maleki left the department, Rebecca Lindell, the new Director of Undergraduate Laboratories, stepped in. Other members of the team included two graduate students and four undergraduate students. During the summer of 1999 the core members of the Development Team met and discussed what topics should be included in the studio curriculum. In the Fall, Chris Sorensen began designing activities which corresponded with the topics. The student members of the team divided into two groups - Engineering Physics I (EPI) and Engineering Physics II (EPII) – built the experiments, and tested them. When equipment needed to be built, we discussed what we needed with the head of the department machine shop and tested the proto-type and the final product. Chris Sorensen then wrote the student manual of activities. Some of the activities are very quick, “aha!” type visualizations of the concepts. Others were more involved, and required data collection and analysis. Also during the Fall, the EPI laboratory room was renovated to be used as the Studio room. In January 2000, with three-quarters of the activities designed and in the manual, New Studio was implemented for the students enrolled in EPI. This was the off-sequence course. The number of students who enroll in EPI off-sequence is approximately half the number who enroll on-sequence. With fewer students involved, and thus fewer instructors, problems such as this activity takes too long or the equipment doesn’t work as designed could be more easily solved as they arose. EPII was implemented in the Fall of 2000.

1.2 *Research Questions*

In the evaluation of the change from the traditional format to the New Studio format and K-State, much can be learned. While not ideal, the format may be suitable for adoption by other institutions which have a limited budget and cannot afford to make huge changes but would like to improve their programs by utilizing a more interactive, hands-on curriculum. Understanding student reactions toward a change in curriculum such as this, as well as changes in student learning may be beneficial to the development and implementation of other materials. Finally, understanding how instructors, and in particular faculty, react toward changes in curriculum could effect how the physics education research community presents new ideas to the physics community at large.

1.2.1 *What perceptions do students enrolled in Engineering Physics have of the course in its new format?*

Students are aware of how Engineering Physics was taught in the past from their friends and colleagues who have taken the course before. How they react to the change in format is important in determining its effectiveness in achieving the goals described above. Also, a student's comfort level in a learning environment will effect how well that student will learn the material being presented. Ascertaining student perceptions will assist in making improvements to the new format.

1.2.2 *What perceptions do instructors teaching Engineering Physics have of the course in its new format?*

In the past, at K-State, faculty have only been involved in the recitation – or problem solving – aspect of Engineering Physics. Likewise, the graduate and undergraduate students have only been involved in the laboratory aspect. How the instructors perceive their new roles in Studio and how they react to it can influence the learning environment for the students. Understanding these perceptions and working with them can help achieve the goals described above.

1.2.3 *From what part of the course do students gain their physics knowledge?*

If all of the students gain all, or most, of their knowledge from the lecture portion of the course, or from solving the homework problems, then it may not have been worth the time, money and effort put into making the change. Also, what students do to learn physics will reflect upon how they are assessed. If the students have not changed how they study and learn physics, despite the change in the course format, then perhaps the change is ineffectual and should be re-evaluated. Understanding what students are doing to learn physics will give further insights into the effectiveness of the new format.

1.2.4 *What gains (or losses) have students made in their knowledge of physics?*

The primary goal is to improve conceptual understanding of physical concepts. Evaluating student conceptual gains using pre- and post instructional surveys will help determine this. Student performance on more traditional problems can also give insight into their conceptual understanding.

1.3 *Summary*

At Kansas State University, we have developed a new method of teaching introductory, calculus-based physics which incorporates some of the innovative teaching methods developed by the Physics Education Research Community. We have eliminated the bad, the disconnection between the lecture and laboratory portions of the course, but kept the good, small group learning and student-teacher interaction. This change has been brought about by re-structuring the format of the class and redesigning how it is being taught. The evaluation of this change is the focus of this document.

Chapter Two: Literature Review

At Kansas State University, the physics department is responsible for providing students who are studying to be engineers and physicists with the framework of how a scientist, and in particular a physicist, thinks about the world in which we live. This has been done by providing the students with a set of experiences designed to guide them into this mode of thinking. This sequence of experiences is called a curriculum (Smith, Stanley, & Shores 1957). This curriculum is not only the content of the courses, but also the method in which it is taught (Ryan & Cooper 1972). At Kansas State we have changed the curriculum on the calculus based introductory physics courses by keeping the main content the same, but altering the methods used to teach it. This change is grounded in what we understand about how students learn and develop their reasoning skills.

2.1 *The Development of Reasoning*

In Physics Education Research, we are concerned with how people learn physics. The root of learning physics is learning in general. Many different theories exist on how people learn and develop their reasoning skills. The theory most commonly embraced by Physics Education Researchers today is Constructivism. Constructivism is built on the theories of cognitive development of Jean Piaget.

2.1.1 *Jean Piaget*

Jean Piaget, a Swiss psychologist and epistemologist, began his study of the origins of human knowledge in the first part of the 20^{th} century. He was interested in understanding how the human mind develops knowledge, i.e. how do we become aware of something and how we use that awareness. To Piaget, knowledge is a dynamic process. We do not wake up one morning and suddenly have knowledge, but rather, we develop it over time as we have new experiences and make new observations. The new experiences must fit with the old, and so it is an ever changing process (Richmond, 1970). Over the years, Piaget generated a large body of concepts and theories concerning the development of knowledge and reasoning. Only one of these concepts, stages in the development of schemes, will be discussed here.

A scheme is a fundamental unit of knowing. It is a mental action that can be used to function in the world. A person progresses from one scheme to the next in a gradual process where each successive scheme is more complete than the one before (Karplus, Fuller, Renner, Collea, & Paldy, 1975). Piaget classified these schemes into five stages of cognitive development, as shown in the table below.

Table 2.1 The Stages of Cognitive Development (Gorman, 1972)

Stage	Characteristics	Approximate Age Range (years)
Sensori-motor	Sensori-motor reflexes and habits Awareness of permanent object Use of means to gain ends	0 to 2
Symbolic thought	Language Symbolic play	2 to 4
Intuitive thought	Syncretism of understanding Transductive reasoning	4 to 7
Concrete operations	Classifying and ordering Decentering and coordination Reversibility Inductive reasoning	7 to 12
Formal operations	Hypothetico-deductive thinking Apstract and formal thought All possible combinations Control of variables Verification of statements Proportionality Integrated system of operations and transformations	12 and up

In Piaget's study, children reached the formal reasoning stage of cognitive development by the time they were age 12. Several outside studies, however, have shown that college students fall into both the concrete reasoning and the formal reasoning stages of development, as well as a combination, or transitional, stage (McKinnon & Renner, 1971; Renner & Lawson, 1973a, 1973b). McKinnon and Renner (1971) were concerned with college freshman and their ability to think logically. They gave 131 students tasks to complete. These tasks were designed by Piaget to determine the stages of cognitive development and at what age changes in cognitive development occurred. They found that 50% of the students were concrete thinkers. In addition, 25% of the students had not fully met the criteria, as described in Table 2.3, of formal thinkers. These students could be considered to be transitional in their reasoning. They concluded that the students, overall, were not formal reasoners. Renner and Lawson (1973b) gave similar tasks to 99 11th grade students and 97 12th grade students as well as to 185 first year college students with similar results. Because of these results, concrete and formal stages of development should be of interest to the introductory college educator.

Three schemes which are characteristic of the cognitive development stage concrete reasoning are: Class Inclusion, Conservation, and Serial Ordering. They are listed, with a brief description, in Table 2.2 below.

Table 2.2 Concrete Schemes

Title	Description
Class Inclusion	Uses simple classifications and generalizations
Conservation	Applies conservation reasoning
Serial Ordering	Arranges a set of objects of data in serial order and establishes a one-to-one correspondence

With these reasoning skills, a person can:

(a) use concepts that directly refer to familiar actions, and can be explained by association;

(b) follow step-by-step instructions if each step is completely specified;

(c) relate one's own viewpoint to that of another in a simple situation.

However, a person with concrete reasoning skills also:

(d) unsystematically searches for and identifies some variables which influence a phenomenon;

(e) does not consider all possibilities when making observations and drawing inferences from them;

(f) answers difficult problems by using incorrect, but related algorithms;

(g) processes information, but is unaware of his/her own reasoning.

Thus, concrete reasoners are limited in their reasoning ability.

On the other hand, schemes which are characteristic of the cognitive development stage formal reasoning are: Combinatorial Reasoning, Separation and Control of Variables, Proportional Reasoning, Probabilistic Reasoning, and Correlational Reasoning. They are listed, with a brief description in Table 2.3 below.

Table 2.3 Formal Schemes

Title	Description
Combinatorial Reasoning	Systematically considers all possible relations of experimental or theoretical conditions
Separation and Control of Variables	Recognizes the necessity of taking into consideration all the known variables and designing a test that controls all variables except the one being investigated
Proportional Reasoning	Recognizes and interprets relationships in situations described by observable or abstract variables
Probabilistic Reasoning	Recognizes the fact that natural phenomena are probabilistic in character, that any conclusions must involve probabilities, and that useful quantitative relationships, or ratios, can be derived
Correlational Reasoning	Recognizes relationships by comparing the number of confirming and disconfirming cases.

With these reasoning skills, a person can:

(a) reason with concepts, relationships, abstract properties, axioms and theories;

(b) use symbols to express ideas;

(c) use the formal schemes in addition to the concrete schemes described above;

(d) plan a lengthy procedure given certain overall goals and resources;

(e) actively check conclusions by appealing to other known information.

To move from one scheme to the next, as well as one stage to the next, a person must assimilate new information into the old. For this to occur, old ideas must be modified to accommodate the new experiences. Intelligent knowing is a balance between assimilation, incorporating the information, and accommodation. Assimilation is when the information is incorporated into body of knowledge already held. Accommodation is the reconciling of any differences there may be between the new knowledge and what already existed (Karplus, et al, 1975). If the two are balanced, then a person is in a state of equilibrium. If they are not, then the person is in disequilibrium and the process of regaining the balance moves them to the next scheme. Some states of equilibrium are more stable than others. For example, a ball sitting inside a bowl is much more stable than a ball sitting on top of an upturned bowl. The ball on top will lose its equilibrium with a small nudge, however, it takes much effort to permanently disturb the ball inside the bowl. Knowledge equilibrium is much the same. If major disequilibrium occurs, then the process of reorganizing schemes can move the person into the next stage of cognitive development (Richmond, 1970).

If a large majority of college students are still in the concrete operational stage of cognitive development, then they will have great difficulty grasping ideas and concepts which are abstract and require formal reasoning skills. What concrete reasoners do learn, they will learn from their direct interaction with the materials at hand. Consequently, by providing them with hands-on activities, which require them to use the skills they have, students can have experiences which need to be assimilated and accommodated into their present schemes. This gives them a disequilibrium which, by resolving, can help them move into the formal operational stage. These new found skills enable the students to better grasp the abstract ideas they are trying to learn (Renner & Lawson, 1973b).

The research done by Piaget into how individuals develop reasoning skills, and thus knowledge, is a foundation for scholars around the world who continue to study what Piaget's epistemology means for education. These scholars are known as "constructivists" for they are concerned with how people "construct" their knowledge (Karplus et al, 1975).

2.1.2 *Constructivism*

The term "constructivism" is used to describe a large number of different theories which fall under the general thought that knowledge is constructed (Phillips, 1995). Rather than receiving knowledge as a transmission of information already complete and ready to use, people build their knowledge on the foundation of what they have previously learned. People approach a situation with prior knowledge influencing them (Hoover, 1996). For example, students in a physics class will apply what they already know about how objects react when moving in a circle based on their previous experience of how their bodies react when they are sitting in car going around a sharp turn. The different theories of constructivism are often delineated by adjectives which describe their primary focus. Personal, Radical, and Social are three of the different schools of thought about constructivism.

Personal Constructivism focuses on the idea that knowledge is constructed to meet the needs of the individual and is based on Piaget's theories of cognitive development discussed in the previous section (Bodner, Klobuchar & Geelan, 2001). An example of personal constructivism would be the evaluation of films based on the actors involved. If a movie-goer believed that Meg Ryan only acts in romantic films, then he/she would assume that "Courage Under Fire" is also a romantic film instead of a political drama. This viewer would then try to assimilate what he/she sees into the known framework of a romantic drama with little success. This would cause the viewer to reassess his/her knowledge of the types of films in which Meg Ryan acts.

Radical Constructivism is also focused on the individual actively involved in constructing his/her own knowledge. However, it adds that the knowledge must fit into the real world of the individual and make sense. That is, the knowledge is only valid within the individual's experience, and it is subjective to that individual (von Glasersfeld, 1992). An example of Radical Constructivism would be a child dealing with a pesky bee. The child has been told by his/her parent that if the bee stings, it will hurt. However, the child does not know this until he/she steps on the bee and is stung.

The third example focuses on the environment in which the knowledge is formed and how this environment may influence the individual. It is called Social Constructivism (Bodner, Klobuchar & Geelan, 2001). Social Constructivism would occur when a group of people collaborate to solve a problem. Each person brings a little bit to the conversation, and together they can build a solution which each would have been unable to do alone. For example, the members of a jury for a court of law will have each listened to a case, but will bring their individual experiences to the discussion to determine if the accused is guilty.

2.1.3 *Impact of Constructivism on Physics Education Research*

Over the past thirty years physicists have been researching how students learn physics. Students come into the physics classroom with pre-formed ideas about how the world around them works. These ideas are based on the experiences they have encountered throughout their lives and are often referred to as common sense beliefs (Halloun & Hestenes, 1985) or preconceptions (Redish, 1994). The students use this background information to make sense of what they are hearing in the physics classroom (Halloun & Hestenes, 1985). In 1994, E. F. Redish summarized the research into four overall principles and thirteen subsequent corollaries. The first principle, which Redish calls "The Construction Principle," is one of the cornerstones of Constructivism: individuals construct their own knowledge. The subsequent corollaries expand the principle and apply it to physics. For example, Corollary 1.2 is implying that students need to be in a particular cognitive stage in order to be receptive to learning physics. The remaining principles and corollaries further expand the idea that knowledge is constructed by the individual by explicitly stating smaller ideas which substantiate the initial statement. The principles and corollaries are compiled below.

> Principle 1: People tend to organize their experiences and observations into patterns or mental models.
>
> > Corollary 1.1: The goal of physics teaching is to have students build the proper mental models for doing physics.
> >
> > Corollary 1.2: It is not sufficient for students to "know the relevant correct statements of physics. They also have to be able to gain access to them at the appropriate times; and they have to have methods of cross checking and evaluating to be certain that the result they have called up is truly relevant.
> >
> > Corollary 1.3: The student is not a tabula rasa (blank slate). Each one comes to us having had experiences with the

physical world and having organized these experiences into mental models.

Corollary 1.4: Mental models must be built. People learn better by doing than by watching something being done.

Corollary 1.5: Many of our students do not have appropriate mental models for what it means to learn physics.

Principle 2: It is reasonably easy to learn something that matches or extends an existing mental model.

Corollary 2.1: It is hard to learn something we do not almost already know.

Corollary 2.2: Much of our learning is done by analogy.

Corollary 2.3: "Touchstone" problems and examples are very important.

Principle 3: It is very difficult to change an established mental model substantially.

Corollary 3.1: In order to change an existing mental model the proposed replacement must have the following characteristics:

(a) It must be understandable.
(b) It must be plausible.
(c) There must be a strong conflict with predictions based on the existing model.
(d) The new model must be seen as useful.

Principle 4: Since each individual constructs his or her own mental ecology, different students have different mental models for physical phenomena and different mental models for learning.

Corollary 4.1: People have different styles of learning.

Corollary 4.2: There is no unique answer to the question: What is the best way to teach a particular subject?

Corollary 4.3: Our own personal experiences may be a very poor guide for telling us what to do for our students.

Corollary 4.4: The information about the state of our students knowledge is contained within them. If we want to know what they know, we not only have to ask then, we have to listen to them!

Through the results of the research that has been done, physicists have come to realize that how physics has been taught in the past is ineffectual. Students leave the physics classroom holding the same misconceptions as they did when they entered. Research done at the University of Washington concerning student understanding of velocity and acceleration is one illustration of this. Students were asked to complete some modified Piagetian tasks on motion as well as tasks which were developed at Washington. The students were interviewed pre- and post-instruction. While there was some change, students after instruction still had difficulty discriminating between position and velocity, and between velocity and acceleration (Trowbridge & McDermott, 1980, 1981). Students are not “blank slates” on which the instructors can write their knowledge, but rather, they are individuals who have pre-formed “mental models” which may, or may not, agree with the information imparted by the instructor. For this reason, instructors are moving away from the “teacher-centered” lecture method of teaching physics and adopting various “student-centered” methods instead. In student-centered methods, instead of “just sitting there,” as most students do during a lecture, students are actively involved in their learning (Zollman, 1996). This involvement could be as simple as adding Peer Instruction to the lecture, or as complex as restructuring the course into a learning cycle format.

Peer Instruction was designed by Eric Mazur at Harvard University during the late 1980s and was implemented in 1991 (Crouch & Mazur, 2001). Mazur was prompted to make a change in his teaching style after reading articles by I. A. Halloun and D. Hestenes (Mazur, 1992). In their articles, Halloun and Hestenes (1985a, 1985b) describe the development of a multiple-choice survey which probes student conceptual understanding of Newtonian Physics. They also discuss the lack of conceptual understanding their students at Arizona State University display. Mazur gave the survey to his students at Harvard and discovered that they displayed a lack of understanding similar to Halloun and Hestenes' students. He found this experience to be eye-opening (Mazur, 1992). In Peer Instruction, the instructor divides the lecture time into short segments and focuses each segment on a core concept. At the end of each segment, students are asked a multiple-choice question, given one minute to answer individually, and report the answer to the instructor. They are then given a few minutes to convince their neighbors that their answer is the correct answer. At the end of the discussion period, the students are asked to answer individually the question given. Usually, the number of students answering the question correctly increases. The instructor then explains the correct answer to the question and moves on to the next core concept. Peer Instruction was designed to be used in Harvard's large introductory lectures, but it has been modified and used successfully elsewhere in both introductory and upper level courses (Crouch & Mazur, 2001). This method of instruction allows students to build on the knowledge they already have. By breaking it up into small, core concepts, concrete reasoners have been better able to fit the information together. Also, by discussing the concepts with their neighbors, students can experience the disequilibrium which is so important to assimilation and accommodation of knowledge discussed by Piaget.

The Learning Cycle is a method of teaching which focuses the act of learning on the student rather than the instructor. The basic cycle is three phases – exploration, concept introduction, and application. In the first phase, the students develop their own ideas about certain concepts by performing hands-on activities and answering questions, posed by the instructor, which are designed to make them think about what they are doing. The students then move into the second phase. Here, new concepts are defined and related back to the activities done in the exploration. In the third phase, students apply the concepts and skills they have just learned to performing a new activity. This activity, or set of activities, can lead into other activities which explore new ideas. Thus, the cycle continues (Karplus et al, 1975).

One example of an adaptation of the Learning Cycle is the Concepts of Physics course at Kansas State University. Concepts of Physics is designed for students majoring in elementary education. The course enrollment is typically about 100 students and is, thus, too large to utilize fully the Learning Cycle where much student-teacher interaction is needed. Instead, the course is divided into 15 week-long activity-based units. During the first half of the week the students are to go to the Physics Activities Center, an open laboratory environment, and work through experiments with a worksheet which guides them through the exploratory activities. Students work at their own pace, either individually or in small groups. On Wednesdays, the students attend class and the instructor introduces the concepts which explains what they have just explored in the Activities Center. The second half of the week is devoted to application of the concepts just learned. The students, once again, are to go to the Activities Center to work on hands-on activities to further develop the concepts. Friday's class time is devoted to student questions about the material for the week. Monday's class time is used to answer any further student questions and to summarize the unit of the previous week. Any in-class examinations are given on Mondays. The cycle for the next unit then begins in the Activities Center. An illustration of the weekly schedule is shown in Table 2.4 (Zollman, 1990).

Table 2.4 Schedule for the Learning Cycle (Zollman, 1990)

	In Activities Center	In Large Class Meetings
Monday PM	Exploration	Further questions and applications
Tuesday	Exploration	
Wednesday AM	Exploration	Concept introduction
Wednesday PM	Application	
Thursday	Application	
Friday AM	Applicaiton	Further applications
Monday AM		Tests, discussion of student question, summary of the unit

The Learning Cycle, like Peer Instruction, is geared toward assisting the concrete reasoner to construct knowledge. The cycle breaks the lesson down into small steps which the concrete reasoner can follow and more easily. Also, the exploration can cause the disequilibrium similar to how the peer discussion can in Peer Instruction.

2.1.4 *Relevant Difficulties in Engineering Physics at Kansas State*

At Kansas State University, while no formal evaluation was done, it had become evident that the students enrolled in the Engineering Physics courses were having conceptual difficulties. These students were being taught in the traditional lecture/recitation/laboratory format. The difficulties they were having were similar to those at Arizona State University and Harvard University as well as elsewhere across the nation. For several years, beginning the fall semester of 1994, two questions specifically pertaining to the laboratory were added to the standardized course evaluation form utilized by Kansas State University. Some of these difficulties could be related to reasoning skills, or stage of cognitive development, of the students. Lectures frequently do not provide the learning environment appropriate for concrete reasoners. The resulting analysis of the course evaluations showed there to be significant student dissatisfaction with the format of the course and that the students felt the lecture and the laboratory were not coordinated or compatible. Also a general consensus, gleaned from conversations with students, faculty and teaching assistants, was that students had difficulty connecting the concepts learned in lecture with the homework discussed in recitation and the experiments done in the laboratories (Sorensen & Maleki, 1998).

2.2 *Curriculum Development for Calculus Based Physics Courses*

Over the past thirty years or so, physicists have begun to recognize that the "traditional" lecture, laboratory, and perhaps recitation method of teaching physics is not reaching the majority of the students enrolled in introductory physics courses. Consequently, research on how people learn, and especially how people learn physics, has been done and other methods have been developed. McDermott and Trowbridge (1980, 1981), at the University of Washington, for example, researched student understanding of velocity and acceleration. Their research precipitated the development of materials for teaching physics to pre-service elementary school teachers. Since these methods incorporate the idea that the learning must be done by the individual and thus the individual is "actively" involved in his/her learning, these methods are often referred to as methods of interactive-engagement or active learning. Of the methods which have been developed, three main methods have been used and adapted. They are: Workshop Physics, Studio Physics, and SCALE-UP (Student-Centered Activities for Large Enrollment University Physics).

2.2.1 *Workshop Physics*

In 1985, Priscilla Laws and some of her colleagues at Dickinson College in Carlisle, Pennsylvania determined that their students were no different than students at other institutions in their lack of properly understanding the Newtonian world view. They decided to abandon the traditional lecture and laboratory format and adopt a workshop-style format combining hands-on experience and theoretical discussions. They applied for, and received, a three-year Fund for the Improvement of Postsecondary Education (FIPSE) grant from the Department of Education to develop the materials. The summer of 1987 was spent drafting the materials and in the Fall of 1987 the Workshop Physics program was implemented in both the calculus-based and non-calculus-based introductory physics courses at Dickinson (Laws, 1991b).

Workshop Physics meets in two-hour blocks three times a week. Each section has up to 24 students enrolled. There are no formal lectures, but rather a set of activities that the students work on with the guidance of one faculty member and two undergraduate teaching assistants. The activities follow a five step learning sequence – prediction, observation, reflection, theory, and application – which is describe in Table 2.5 below (Laws, 1997a, 1997b). By following this sequence, students who are still concrete reasoners have a structure to use to construct their knowledge and develop formal reasoning skills.

Table 2.5 The Workshop Physics Learning Sequence

Prediction	Students predict what will happen in the phenomenon being studied. This gives them an opportunity to consider the pre-formed ideas they have about the phenomenon.
Observation	Students perform hands-on activities to observe the phenomenon.
Reflection	Students reflect on the observations they have made and make adjustments to their predictions.
Theory	Students develop definitions and equations based on historical theory.
Application	Students perform experiments to verify their predictions and apply what they have just learned to solving problems.

The material included in the two semester sequence is approximately three-quarters that of most traditional courses. Material which is normally taught in more depth in the second-year program, such as optics, was eliminated from the introductory course. Topics were included based on their helpfulness in preparing students for further study in physics and engineering. These topics are directly observable, and mathematical and reasoning skills learned from them are applicable to a wide range of other topics (Laws, 1991a).

Table 2.6 Topics included in Workshop Physics by Module

Module 1	Kinematics Newtonian Dynamics
Module 2	Momentum Energy Rotational and harmonic motion Chaos
Module 3	Thermodynamics Kinetic theory Heat engines Nuclear decay Radon monitoring
Module 4	Electrostatics DC circuits Electronics Magnetism

Over the years, the impact of Workshop Physics on student learning and attitudes has been assessed. The students have been given conceptual surveys as well as attitudinal surveys. In 1991, preliminary findings showed that approximately two-thirds of the students at Dickinson College preferred the workshop method as compared to their perception of a lecture course. On conceptual tests, a higher percentage of Workshop Physics students showed mastery of concepts considered difficult due to classic misconceptions. However, conceptual gains were sometimes disappointing, and changes to the curriculum based on Physics Education Research was proposed (Laws, 1991a). Since its inception, many changes have been made to the Workshop Physics curriculum and conceptual gains have improved accordingly. Since 1997, fractional gains

$$< g >= \frac{(post\% - pre\%)}{(100\% - pre\%)} \tag{2.1}$$

on the Force and Motion Conceptual Evaluation (FMCE) have been approximately 0.7 while traditional fractional gains on the same or similar evaluations are approximately 0.2. In electrostatics, similar results have been reported. Students at Dickinson tend to do better on conceptual questions and traditional problem-solving questions, but not on multiple-choice problems as compared to traditional university students (P. W. Laws & H. Pfister, personal communication, 10 April 2001).

2.2.2 *Studio Physics*

At Rensselaer Polytechnic Institute, in Troy, New York, the Studio Model is used to teach many of the introductory classes across the campus. This change from traditional approaches was sparked by the feeling of some professors that there had to be a better way of teaching than the lecture models dominating higher education. In 1993, a panel of experts was brought to the campus to discuss the design of an alternative approach. One of the experts was Priscilla Laws, the primary designer of Workshop Physics. The first Studio course was offered in Calculus in the fall of 1993. The first Studio Physics course was offered the following spring as a pilot study and fully implemented the following fall (Wilson, 2000).

Studio Physics was designed by combining and extending materials from CUPLE, M.U.P.P.E.T., and Workshop Physics (Wilson, 1994). CUPLE, which stands for Comprehensive Unified Physics Learning Environment, is a compilation of many technology-based approaches to teaching physics. The Windows based environment incorporates computer simulations, modeling approaches to problem solving, microcomputer-based data acquisition and analysis with bibliographies and glossaries of materials published by the American Association of Physics Teachers (Cooper, 1997). M.U.P.P.E.T., which stands for the Maryland University Project in Physics and Educational Technology, is a tool which enables introductory physics students to solve problems using computer programming. It was developed in the earlier 1980s and utilizes tools from the Pascal programming language. Using M.U.P.P.E.T., students are able to focus on the physics at hand rather than on the designing of a computer program to use to collect and analyze the data. Students are thus able to solve problems which are more complicated and involved than most introductory students (Redish, 1997). Studio Physics meets in two-hour blocks twice a week. Each section has an approximate enrollment of 60 students. The first 20 minutes of a class are usually spent discussing any concerns the students may have on the homework. Then, a brief presentation of a topic is given and a related laboratory activity performed. The course is team-taught by a faculty member, a graduate student and an undergraduate student. The laboratory activities often give the students hands-on experience with the topic just discussed as well as lead them into the next topic. For example, an activity involving Newton's second law using a hanging spring and a mass leads into the introduction of Hooke's Law (Wilson, 1994). This method incorporates hands-on activities emphasized in the constructivism approach with the benefits of the Learning Cycle. The activities can be quite complicated involving data acquisition with a video camera directly linked to a computer, or as simple as a few bar magnets and a compass. While the amount of in-class time has been reduced from six hours to four, the amount of material covered has not been significantly reduced. The topics included are shown in Table 2.7 by semester course (Cummings, Marx, Thornton & Kuhl, 2000).

Table 2.7 Topics included in Studio Physics by Semester

Physics I	Linear Kinematics/Dynamics and Energy Momentum (p and L) Angular Kinematics/Dynamics, Torque Gravitation Electrostatics
Physics II	Electricity and Magnetism Maxwell's equations Waves and Oscillations Mechanical and E&M Modern/Contemporary Physics Topics

Since the implementation of Studio Physics, a few changes have been made to standardize the courses. While there are approximately 20 sections taught by 10 different instructors there is a course supervisor for each course who oversees the general functions. Every student in Physics I (or Physics II) receives the same syllabus, do the same homework assignments, and take the same exams. In addition to developing the exams, selecting the homework assignments and in-class activities, and providing solutions, the course supervisor prepares the daily mini-lecture to be given in each section. By doing this, some consistency is maintained across the course while still leaving room for the individual instructors to add their own touch (Cummings, et al, 1999).

The Studio Physics course was first evaluated by S. M. A. Cooper the first semester it was fully implemented. She administered pre- and post-instruction conceptual surveys to measure the students' gain in conceptual understanding as well as periodic interviews of a sub-set of students to evaluate their problem solving techniques. At the end of the semester, she asked students for their opinions of the strengths and weaknesses of the course. The results of the conceptual surveys indicated that student understanding was the equivalent to the expected results of a strong traditionally taught course (Cooper, 1997). The fractional gain on the Force Concept Inventory, for example (see eqn. 2.1) was 0.22 (Cummings, et al, 1999). The student reaction to the course was quite positive. They felt that it provided them with direct interaction with instructors as well as other students. This gave them the opportunity to get immediate feedback on any questions as they arose. Students also found the integration of activities with concept introduction to be positive. One aspect which students to be both a strength and a weakness was that learning was no longer the responsibility of the teacher. Another weakness was that some students did not care for the emphasis on computer-based laboratories (Cooper, 1997).

The relatively low fractional gain on the Force Concept Inventory was rather disturbing in view of how the course was designed to be interactive. In comparison with other curricula, such as Workshop Physics, which have been more successful, it was noted that most of the activities tended to be standard, traditional laboratories modified to utilize computers. Unlike the other curricula, the activities did not directly address the misconceptions often held by students, nor provide the cognitive conflict needed to overcome them. For this reason, a pilot study was done during the spring semester of 1998 to incorporate into a few sections of Studio Physics two techniques developed by the physics education community to engage students in their own learning process. The two techniques were Interactive Lecture Demonstrations and Cooperative Group Problem Solving (Cummings et al, 1999). Interactive Lecture Demonstrations (ILDs) were designed by R. K. Thornton and D. R. Sokoloff (1997) to stimulate an active learning environment within a large lecture. It is similar to Peer Instruction developed by Eric

Mazur and discussed above. However, instead of asking questions to be discussed, an experiment is the focal point. The instructor performs the experiment without making measurements and implements the discussion. After gleaning common predictions, the instructor performs the experiment again, but uses computer data acquisition methods and displays the data to the students. The instructor then discusses the situation and relates it to other similar situations. Cooperative Group Problem Solving (CGPS) was designed at the University of Minnesota to assist large introductory physics course students to integrate the conceptual and mathematical aspects of problem solving (Heller, Keith, & Anderson, 1992). Students gain problem solving skills by working together is small groups utilizing a prescribed strategy to solve problems. The problems are designed so that students will utilize their conceptual knowledge of physics rather than seeking an equation and inserting numbers.

To evaluate the changes, the pre- and post-instruction conceptual surveys were again administered to the students. The fractional gain on the Force Concept Inventory of the students who were enrolled in the sections which were not modified remained approximately the same, $\langle g \rangle = 0.18$. However, the fractional gains of the students who were exposed to either the ILDs or CGPS improved, $\langle g \rangle = 0.35$ and 0.36 respectively. This change implies that, with the adoption of research-based activities, Studio Physics can be improved (Cummings et al, 1999).

2.2.3 *SCALE-UP*

Student-Centered Activities for Large Enrollment University Physics (SCALE-UP) is an outgrowth from the Integrated Math, Physics, Engineering, and Chemistry

(IMPEC) project at North Carolina State University (Beichner, Saul, Allain, Deardorff, & Abbott, 2000a). The IMPEC project, begun the fall of 1994, attempted to reduce the attrition rate of freshman engineering students by combining the courses usually taken during the first year of an engineering curriculum (Felder, Bernold, Burniston, Dail, & Gastineau, 1996). The courses included differential and integral calculus, general chemistry, the first semester of physics, and a general introduction to engineering. Except for a wet chemistry laboratory, all of the in-class work was done in the same room. The students were placed into groups of three to work on homework and laboratory assignments. The groups were maintained for all courses and throughout the semester. For the physics portion, instead of traditional, lecture-based instruction, different aspects of research-based approaches to teaching and learning were combined and utilized. These approaches included activity-based pedagogies such as Workshop Physics and Studio Physics, collaborative learning, context-rich problems, the use of technology, and integration of the curricula. Activities were developed to maintain student interest and reduce the amount of time spent lecturing (Beichner et al., 1999). IMPEC is no longer in operation. The group of faculty involved decided that, while it demonstrated what they wanted to show, it would not be very transferable in its final form. Thus, the integration ended when the grant ended and the physics course moved into SCALE-UP (R. J. Beichner, personal communication, 7 September 2001).

Teaching students in the interactive environment of IMPEC was a success, but only served 36 students at a time. In a large university, where 1000 students enroll in physics every semester, the goal was to find a way to have similar success with classes of 100 students (Beichner, 1999b). SCALE-UP was implemented in three phases. The first phase, in the fall of 1997, was held in a traditional lecture hall that had long, narrow tables and fixed seating for 77 students (R. J. Beichner, personal communication, 7 September 2001). This arrangement was unsatisfactory because students who did not wish to participate could sit in the center of the room and be inaccessible to the instructor (Beichner, 1999a). In the second phase, the following year, SCALE-UP was taught in a renovated classroom serving 54 students. The students sat in three teams of three around round tables. The round tables allowed students to easily work in their teams or as a large group of nine. Also, the instructors could more easily circulate throughout the room to reach each student (Beichner, 1999a). Due to construction delays, the renovation of a classroom to seat 99 students was not completed as expected. A class of 54 students moved into the large classroom in October 2000, and full sections of 99 students started January 2001. Thus, the third stage of implementation was complete (Beichner, personal communication, 7 September 2001).

The structure of SCALE-UP is similar to IMPEC in that the lecture and laboratory have been combined into a single interactive classroom. The students meet for five hours during the week in two two-hour sessions and one one-hour session. The course is team taught by a faculty member and two assistant graduate or undergraduate students (J. S. Risley, personal communication, 30 April 2001). The instruction is centered around Tangibles, which are short, hands-on activities, and Ponderables, which are interesting questions to consider. A tangible for circuits, for example, would involve drawing as many different possible circuits using a single battery and three lightbulbs. After making the sketches, the students are then asked to construct the circuits and make observations. Often, results from each team, or from each table, are recorded on whiteboards near their tables and discussed with the rest of the class. A ponderable could be a question which has the students consider how much the image on a computer screen would shift if the monitor is rotated from east to west (http://courses.ncsu.edu:8020/py208/lec/011/index.html). The materials target known areas of difficulty and were either developed in house or modified from existing materials such as Mazur's Peer Instruction Questions, Workshop Physics activities, or Tutorials from the University of Washington. In addition to the tangibles, students also periodically do longer, group-based laboratories and formal reports. All materials, including homework, are web-based except for the exams (Beichner, et al., 2000a). A typical day in a SCALE-UP classroom would start with a short review of what was done in the previous class. Then new concepts would be introduced in a short lecture which leads into the day's tangibles and ponderables. Tangibles and ponderables may be intermixed so that students can build on their ideas in a learning sequence similar to that described in Table 2.5. At the end of the day, the class will be brought together for a brief summary of the day's activities (personal observations, 30 April 2001).

As illustrated in Table 2.8, the topics included in SCALE-UP are reduced from those often taught in traditional, lecture coursed at other universities. However, at North Carolina State University, the topics which have been eliminated, such as fluids and thermodynamics, had previously been removed from the traditional course. Consequently, the students enrolled in SCALE-UP are not being deprived of topics their counterparts in the traditional course are learning (R. J. Beichner, personal communication, 30 April 2001).

Table 2.8 Topics included in SCALE-UP by Semester

Physics I (PY 205)	Basic Kinematics Forces Energy Waves
Physics II (PY 208)	Basic Electricity and Magnetism Geometric Optics Modern Physics

As SCALE-UP has been developed, it has been evaluated for its effectiveness in student learning gains and attitudinal changes. A variety of methods have been used including, but not limited to, pre- and post-instruction conceptual surveys, portfolios of student work, and student interviews. Students enrolled in the 1st semester course were given the Force Concept Inventory (FCI) and the Force and Motion Concept Evaluation (FMCE). The fractional gains (see eqn. 2.1) of the SCALE-UP students were approximately twice that of their traditional counterparts. The second semester students were given the Conceptual Survey of Electricity and Magnetism (CSEM) and Determining and Interpreting Resistive Electric Circuits Concept Test (DIRECT) to evaluate their conceptual gains. Again, the SCALE-UP students had fractional gains of approximately twice that of the traditional students. See Table 2.9 and 2.10 for actual fractional gain scores. Since some of the SCALE-UP classes were not given the conceptual surveys pre-instruction, their fractional gains are not reported here (Saul, Deardorff, Abbott, Allain, & Beichner, 2000).

Table 2.9 Fractional Gains from 1st Semester Classes (Mechanics)

	FCI	FMCE
Traditional Lecture Classes	0.21	.011
SCALE-UP Fall 1998	0.42	
SCALE-UP Spring 1999		0.39

Table 2.10 Fractional Gains from 2nd Semester Classes (Electricity and Magnetism)

	CSEM	DIRECT
Traditional Lecture Classes	0.14	0.10
SCALE-UP Fall 1998	0.21	0.17
SCALE-UP Fall 1999	0.36	

The problem solving skills of the SCALE-UP students were also compared to those of the traditional students during the 1998-1999 academic year. Student performance on exam problems written for the traditional course were examined. SCALE-UP students out-performed their peers 88% of the time during the fall semester and 69% of the time during the spring. The traditional students tended to do better on the one-step problems such as unit conversions (Saul, et al., 2000).

Based on student interviews, the overall student reaction to SCALE-UP, in the 1998-1999 academic year was positive. They liked the in-class group work and the fact the instructors knew their names. They felt SCALE-UP was more effective for conceptual learning than the traditional course. Also, they appreciated the fact that more emphasis was put on understanding concepts in their course as compared to the traditional course (Saul, et al., 2000). In addition to the interview, the SCALE-UP students were given the Maryland Physics Expectations (MPEX) Survey (Beichner, 1999a). The MPEX was developed at the University of Maryland to measure student attitudes about course content and science and learning in general. It is usually administered pre- and post-instruction to determine how student attitudes change with instruction. Students taught in a predominantly traditional manner tended to show a decrease in their expectations. Therefore, little to no change is a good result (Redish, Saul, & Steinberg, 1998). In the spring of 1999, the SCALE-UP students showed no significant change in their overall MPEX score (Beichner, 1999a).

Finally, the failure rates of the two courses were compared as a method of evaluating students' learning experience in physics. Traditionally, students find introductory physics to be extremely difficult, formula orientated and boring. Overall, the failure rate of the traditional students was higher than that of the SCALE-UP students as illustrated in Table 2.11 (Saul, et al., 2000). This change in failure rate, particularly for women and minorities, implies that the interactive approach of SCALE-UP is a positive influence on student learning experiences.

Table 2.11 Student Failure Rates in 1998-1999

	Traditional Course	SCALE-UP
Overall	25%	13%
Women	27%	9%
Minorities	48%	8%

2.3 *Assessment*

Various assessments which measure student conceptual understanding have been developed and are available for use in classroom situations. Table 2.12 contains a listing of twelve evaluation instruments which have been designed to measure student understanding of different concepts taught in introductory physics courses.

Table 2.12 Some Conceptual Assessment Instruments

Name	Acronym	Developers
Tools for Scientific Thinking: Force and Motion Conceptual Evaluation	FMCE	Ronald Thornton at the Center for Science and Math Teaching at Tufts University and David Sokoloff at the University of Oregon
The Mechanics Baseline Test	MBT	David Hestenes and MalcolmWells at Arizona State University
The Force Concept Inventory	FCI	David Hestenes, Malcolm Wells, Gregg Swackhamer, and Ibrahim Halloun at Arizona State University
Test of Understanding Graphs in Kinematics	TUG-K	Robert Beichner at North Carolina State University
The Heat and Temperature Conceptual Evaluation	HCTE	Ronald Thornton at the Center for Science and Math Teaching at Tufts University and David Sokoloff at the University of Oregon
Conceptual Survey in Electricity	CSE	David Maloney at Indiana University-Purdue University at Fort Wayne, Alan van Heuvelen at Ohio State University, Curt Hieggelke at Joliet Junior College, and Tom O'Kuma at Lee College
Conceptual Survey in Magnetism	CSM	David Maloney at Indiana University-Purdue University at Fort Wayne, Alan van Heuvelen at Ohio State University, Curt Hieggelke at Joliet Junior College, and Tom O'Kuma at Lee College
Diagnostic Exam for an undergraduate, introductory Electricity and Magnetism Course	DEEM	Jeff Marx at the University at Oregon and Jack Wilson at Rensselaer Polytechnic Institute
Determining and Interpreting Resistive Electric Circuits Concepts Test	DIRECT 1.2	Paula Engelgardt and Robert Beichner at North Carolina State University
The Electric Circuits Conceptual Evaluation	ECCE	Ronald Thornton at the Center for Science and Math Teaching at Tufts University and David Sokoloff at the University of Oregon
Light and Optics Conceptual Evaluation	LOCE	Ronald Thornton at the Center for Science and Math Teaching at Tufts University and David Sokoloff at the University of Oregon
Optics ConcepTest		Eric Mazur at Harvard University

Chapter Three: Methodology

In order to undertake this investigation, several methods of data collection were used. Written, multiple-choice conceptual surveys – pre- and post-instruction – were used to try measure student conceptual gains. Written exit surveys were used to ascertain student opinions and attitudes related to the course in its new structure. Multiple interviews of student volunteers tracked student perceptions of the course throughout the semester. Multiple interviews of the faculty and teaching assistants involved tracked instructor perceptions of the course. Finally, averages of individual questions on exams given by the primary faculty member were tallied. All of these methods of data collection provide different viewpoints into the fabric of the Engineering Physics course.

3.1 *Written Surveys: Concepts*

Two different conceptual surveys were given to all students enrolled in the Engineering Physics courses: the Force Concept Inventory (FCI) and a conglomerate survey referred to as the Engineering Physics II Conceptual Survey (EPIICS). Prior to administering any survey the students were given the option of not participating. Most chose to complete the surveys.

3.1.1 *The Force Concept Inventory*

The Force Concept Inventory (FCI) was written by David Hestenes, Malcolm Wells, and Gregg Swackhamer. Their intent was to develop an instrument which would probe the belief systems students hold concerning force, the primary concept of

Newtonian mechanics. When the FCI was first published in *The Physics Teacher,* it consisted of 29 multiple-choice questions (Hestenes, Wells, & Swackhamer, 1992). It has since evolved to 30 multiple-choice questions. For each question, one choice is the correct Newtonian answer, while the other responses consist of common sense misconceptions that students often hold for the concept being probed. The FCI was developed as an improvement to the Mechanics Diagnostic Test (MDT) designed by I. A. Halloun and D. Hestenes at Arizona State University (Hestenes, Wells, & Swackhamer, 1992). The MDT consists of 36 multiple-choice questions. The questions were constructed to probe student conceptions of motion and to identify common misconceptions. Over a period of three years, the test, in several versions, was given to over 1000 college students enrolled in introductory physics. On the first versions, the questions were open-ended and required a written response. The most common misconception responses were then used as alternate choices to the correct answers on the multiple-choice version. Four different methods were used to establish content validity of the MDT. First, while it was being developed, physics faculty and graduate students were asked to evaluate it. Their suggestions were then used to make modifications. Second, 11 graduate students were asked to take the MDT, and all of their answers corresponded with the correct answers. Third, 22 of the introductory physics students who had taken the test were interviewed to determine if they understood the questions and answers. They did. Finally, the answers of 31 students who earned A's in the course were examined for common misunderstandings which could be due to the form of the questions. No commonalities were found. By statistically analyzing the test results and interviewing a sample of students who had taken the MDT, reliability of the test was established. In the interviews, the students demonstrated that the answers they had given on the MDT reflected the beliefs they held and were not the product of random guessing. This was confirmed when, on subsequent re-testing, there was a high reproducibility of responses (Halloun & Hestenes, 1985a).

Approximately half of the questions on the FCI were taken directly from the MDT while the remaining were developed by Hestenes, Wells, and Swackhamer. These new questions were validated by interviews with high school teachers (D. Hestenes, personal communication, 12 September 2001). Further reliability was established from student interviews and by statistical analysis of test results from high school students in Arizona and Chicago as well as college students enrolled in physics course taught by a variety of professors at Arizona State University (Hestenes, Wells, & Swackhamer, 1992).

The authors of the inventory indicate that the FCI can be used in three ways – as a diagnostic tool, for evaluating instruction, and as a placement exam. As a diagnostic tool, the FCI can help instructors identify and classify the misconceptions which their students hold and which can then be addressed in class. For evaluating instruction, only the post-instruction scores really matter. If the instruction is effective in giving the students an understanding of Newtonian mechanics, then the post-instruction scores should be high. Finally, the FCI should only be used as a placement exam at the college level to determine if students understand introductory physics well enough to be enrolled in a more advanced course (Hestenes, Wells, & Swackhamer, 1992). The questions are designed to probe six different fundamental aspects of force – kinematics, first law, second law, third law, superposition principle, and kinds of force – they recommend that for the best results the survey scores should be interpreted as a single unit. As a whole, "the FCI score is a measure of one's understanding of the Newtonian force concept." (Hestenes & Halloun, 1995).

Since the FCI was first published in 1992, there has been some controversy as to whether or not it actually measures what the authors says it measures – a knowledge of the force concept. Douglas Huffman and Patricia Heller (1995) performed a factor analysis – a statistical technique which indicates how test items are related – on the responses of 750 university students and 145 high school students responses. They determined that, at best, the questions on the FCI were loosely related and, therefore, did not give an overall view of student understanding of the Newtonian force concept. David Hestenes and Ibrahim Halloun (1995) responded that the factor analysis of Huffman and Heller merely strengthened the position that "student belief systems are incoherent" and "can best be described as bundles of loosely related and sometimes inconsistent concepts" (Halloun & Hestenes, 1985b). Despite the controversy, the FCI has been widely used across the country in high school and university physics courses to evaluate the effectiveness of introductory physics instruction. Summative data collected by Richard Hake lead to the conclusion that students who have had interactive-engagement physics instruction tend to show greater gain on the FCI than do students who have had traditional physics instruction (Hake, 1998).

Because of its extensive acceptance, the Development Team decided to use the FCI at Kansas State University as a measurement of the effectiveness of the instruction related to Newton's Laws as it changed from the traditional to the Studio format. The FCI was administered to all students enrolled in Engineering Physics, as a pre- and post-test during the Spring prior to the format change. Since the change was implemented, the FCI has been administered at the beginning of the first semester and approximately three-quarters of the way through that semester – after Newtonian mechanics instruction has been completed. In this way, immediate conceptual changes in student understanding of Newtonian Force can be determined. A copy of the FCI is located in Appendix A.

3.1.2 *The Engineering Physics II Conceptual Survey*

For the second semester course, the Development Team decided that the students should not be asked to complete four separate conceptual surveys for electricity, magnetism, circuits and optics. Administering so many surveys would take too much time away from learning. Also, the students might balk at "yet another survey." Consequently, instead of giving the Conceptual Survey in Electricity (CSE), the Conceptual Survey in Magnetism (CSM), **D**etermining and **I**nterpreting **R**esistive **E**lectric Circuits **C**oncepts **T**est (DIRECT), and either the Optics Conceptual Evaluation or the Optics ConcepTest, a conglomerate survey was developed by selecting from each of the five surveys elements which were deemed, by two independent faculty members of the Kansas State University physics department, as most important concepts the students should understand upon completion of the course. The result was then dubbed the Engineering Physics II Conceptual Survey (EPIICS). A copy of the EPIICS is located in Appendix B.

3.1.2.1 *The Conceptual Survey of Electricity and Magnetism*

The CSE and the CSM were precursors to the Conceptual Survey of Electricity and Magnetism (CSEM) developed by David Maloney, Thomas O'Kuma, Curtis Hieggelke, and Alan Van Heuvelan (2001). Their goal was to devise a single assessment tool that could be used to qualitatively evaluate student pre-and post-instruction knowledge of electricity and magnetism. The initial sets of questions were written at a two-year college physics workshop by a group of experienced college professors. The resulting tests were then administered to students as multiple-choice questions as well as open-ended questions. Revisions based on student data, student explanation of responses and instructor feedback were made. One revision was to combine the two surveys into one overview. The final product is a 32 multiple-choice question survey.

The CSEM was then evaluated for difficulty, validity, and reliability. To test the difficulty of the test questions, the percentage of students who get a test question correct is determined. A difficulty rating will thus range from 0.0 – all students answer incorrectly – to 1.0 – all students answer correctly. The ideal rating is 0.5. The difficulty rating for the CSEM ranged from 0.1 to 0.8. The authors considered this to be reasonable. However, they noted that only a quarter of the questions rated above 0.6 which is fewer than would be preferred. The authors then tested validity – how well the test measures what is says it measures – by having two groups of two-year college physics professors rate each question – on a scale from one to five – for reasonableness and appropriateness. All of the questions were rated as being highly reasonable and appropriate. Finally, the reliability – how well a score can be reproduced under the same conditions – was tested using a statistical test called Kuder-Richardson 20 (KR 20).

Scores on the KR 20 range from 0 to 1.0 where 0.8 to 0.9 indicates high reliability. A cognitive test, such as the CSEM is considered to be well made if it has a score between 0.7 and 0.8. The CSEM score was 0.75. A factor analysis was also done, but with insignificant results.

The CSEM was administered to two groups of college students – algebra/trigonometry-based and calculus-based – at two-year colleges, four-year colleges, and universities. The authors found that, as there was little variance among the scores from the three types of institutions, it was not necessary to indicate results by institution. The pre- and post-test scores are not matched as the authors found there to be little difference between the results of the analysis of matched data and unmatched data. The overall average pre-test scores for the 273 algebra-based students was 25%, while the average post-test score for 262 students was 44%. The calculus-based students averaged 31% (n = 1213) on the pre-test and 47% (n = 1030) on the post-test. The CSEM was also administered to two high school classes with results similar to those of the college students (Maloney, O'Kuma, Hieggelke, & Van Heuvelen, 2001).

3.1.2.2 *Determining and Interpreting Resistive Electric Circuits Concepts Test*

DIRECT was developed by Paula Vetter Engelhardt and Robert J. Beichner (2001) at North Carolina State University. The purpose of the survey was to probe high school and university students' understanding of the concepts of direct current circuits. By examining high school and university textbooks and laboratory manuals as well as having informal discussions with high school and university instructors, the authors determined there were eleven instructional objectives which instructors expect students to understand. An independent panel of twelve high school and university instructors reviewed the resulting list. Open-ended questions were then written for each objective. Originally, three questions, in different modes of representation, were written for each objective. However, the questions for one of the objectives were removed as they provided information needed to answer other questions (Engelhardt & Beichner, 2001). The survey was then given to the independent panel to assess its validity. The panel was asked to match the questions with the objectives. The preferable range of agreement should be between 80% and 90%. The panel found an agreement of 74% (Engelhardt, 1997).

The survey was revised based on suggestions made by members of the panel and then administered to 39 high school students and 40 university students who had already received instruction on the material. Subsequent interviews with some of the students revealed misinterpretations of the wording of some questions. The survey was then further revised and the questions converted into multiple-choice responses. The distracters for the multiple-choice selections were chosen from the responses the students had given on the open-ended survey. The resulting survey had 29 questions. It was administered, post-instruction, to 454 high school students and 681 university students during the Spring of 1995 and evaluated for difficulty, reliability, and validity. The mean score for the high school students was 41% and the university mean was 52%. The average difficulty rating was 0.49 and the KR 20 score was 0.71. Eleven of the high school students and 17 of the university students were interviewed to check validity. The survey was revised once again to standardize the number of possible choices for each question and to reword some questions the students were misinterpreting. During the

Spring of 1996, the final survey was administered to 251 high school students and 441 university students. The high school mean score was 36% and the university mean was 44%. The average difficulty rating was 0.41 and the KR 20 score was 0.70. The validity of the survey was tested by having four graduate students and four professors at North Carolina State University match the questions with the original objectives. There was 63% agreement (Engelhardt, 1997).

3.1.2.3 *Light and Optics Conceptual Evaluation*

Ronald Thornton and David Sokoloff (1997) have been developing a set of curricular materials, called Real-Time Physics, that utilize activity-based learning but is to be used in a traditional course structure in place of the laboratory. The LOCE is an assessment they were developing in conjunction with the activities for light and optics. It has not yet been published.

3.1.2.4 *Optics ConcepTest*

Eric Mazur (1997) created ConcepTests as one part of the instructional materials he developed for Peer Instruction. The purpose of ConcepTests is two fold. First, they stimulate the students to think about the concept at hand, and second, they allow the students and the instructors to assess student understanding of the concept. The Optics ConcepTest is one of 19 published in Peer Instruction: A user's manual.

3.2 *Written Surveys: Opinions*

Since one of the goals of changing the format of the Engineering Physics course was to give the students a better learning experience, both in course content and student attitude toward the course, determining their opinions of the course was essential. Consequently, an exit survey was devised and given to the students during their Studio time, either the last or second to last meeting. Again, the students were informed as to why the survey was being given and that they were under no obligation to complete it. Due to the fact it is given at the end of the semester, some students opted to take the time to study for another class rather than complete the survey. A second goal of the surveys was to get student ideas of what improvements could be made to the course format. Giving the students the opportunity to tell us what they would change, not only reinforced the sense that we cared about what they think, it also gave us valuable suggestions of what we could improve from the student point of view.

For the first two semesters, the survey consisted of seven short answer questions and eight questions based on a Likert scale. Members of the Development Team met to discuss what information we wanted to elicit from the students. The resulting survey was then reviewed by the lead professor of the Physics Education Research Group for clarity and appropriateness. The resulting survey reflected that the Team wanted to know what the students liked and disliked about Studio in general and about working in groups in particular. We also wanted to know what the students would change or not change about Studio. Finally, we asked them what recommendations they would give their friends enrolling in the course in the future. These topics were addressed as open-ended questions. Some of the Likert scale questions were aimed at determining how well the students felt the Studio format met criteria such as coordination between lecture, homework and laboratory work. The remaining questions were concerned with communication among students and between students and instructors. The exit survey also had three demographic questions asking Studio meeting time, major, and gender.

At the end of the third semester of implementation, the exit survey was altered to specifically target a change which had been made to Studio. In addition to a faculty member and a teaching assistant (TA) in the classroom, a second teaching assistant was added. The responsibility of this teaching assistant, called a Class Assistant (CA), was to assist the students while they were working on the activities in Studio. The CA had no responsibilities outside of the classroom. To assess the effectiveness of three instructors in each classroom, one short answer question and five Likert scale questions were added to the survey. The short answer question asked for comments on the helpfulness of each instructor. The Likert scale questions asked about frequency of interaction with each instructor and which of the instructors the students were most comfortable with when interacting about activities, or homework. Complete copies of both surveys are located in Appendix C.

Because the surveys were given during the last, or next to last, meeting time of Studio, there is some concern as to the reliability and validity of the results of the survey. Many students did not come to the last session of Studio and consequently their opinions were not elicited. This concern was a particular issue during the first semester of implementation when the students knew they would not received any grade points for the last day of class. This situation was remedied the following semester by explicitly stating the students would receive a day’s worth of points simply by being there. The lack of attendance may have biased the data as many of the students who were not present were those students who had been doing well in the class and had attended all, or nearly all, sessions. Since the students were allowed three "cut" days, these students chose to cut the last day when they knew no, or very little, new information would be discussed. Consequently, their viewpoints were lost. Also, since the students were not required to complete the survey, many students opted to take the time as an extra half hour to study for other classes rather than give their input. A further concern is how comfortable the students felt in stating their opinions. Even though the surveys were anonymous, they may have felt pressured by the presence of their instructors to give particular answers. Also, they may have responded favorably because they thought that is what we wanted to hear.

3.3 *Student Interviews*

At the beginning of the first and second semesters of implementation students were asked to volunteer to be interviewed periodically throughout the semester for two semesters. Two categories of students were sought: new to Engineering Physics and previously taken Engineering Physics in the traditional format. The purpose of the interviews was to ascertain student perceptions of course content and structure as the course progressed. The interviews were also to ascertain how students approached the exams as the course progressed. That is, did they view the exams as questions which are homework-like problems which they have memorized to pick an equation and plug in numbers or as questions about concepts or ideas they have learned and can apply to any situation? At their first interview, the students were informed about the purpose of the interviews and how the interviews fit into the greater scheme of the evaluation process of the change made to the Engineering Physics course. They were also reminded that if, at any time, they felt uncomfortable with the process they were free to withdraw from the study with no penalty. The interviews were conducted in a semi-structured format. A predetermined set of questions was used as a guide so that certain topics would be included in all interviews. However, students had the opportunity to lead the conversation, thereby sometimes answer questions prior to being asked. Students were interviewed five times during the semester – after each exam except the final. The interviews were usually conducted within a week after the exams were returned to the students. The exams gave a starting point of conversation as well as providing insight into the students' thinking process. The questions pertained to how they felt about the particular exam, what they did to study for the exam, what they were thinking while working on particular questions on the exam, how the questions related to what they did in Studio, and what they thought about Studio itself. The interviews after the first, third, and fifth exams included a sub-set of questions similar to the open-ended questions of the exit survey – and covered likes and dislikes of the Studio format. Minor variations to questions occurred from one exam to the next depending on the time during the semester – comparing opinions at the end of the semester to the beginning – and if there was anything in particular that needed to be targeted. For example, once, questions were asked about a computer simulation activity that had been recently completed. Student interview protocols are located in Appendix D. The interviews were all tape-recorded with varying success.

By the end of the third semester of implementation, 41 students were interviewed for a total of 284 interviews. The number of interviews completed by a single student ranged from two – the student dropped out of the class part way through the semester – to 13 – two students volunteered the first semester and were interviewed five times, failed the course, re-took the course and were interview three times during the semester, passed the course and were interviewed five times while enrolled in the second semester course. See Table 3.1below.

Table 3.1 Number of Students by Number of Interviews

Number of Interviews	Number of Interviewees
2	4
3	1
4	5
5	11
6	1
7	1
9	1
10	15
13	2
total	41

Because all of the students interviewed were volunteers with no external motivation to participate and not a random sample of the general population, there is some concern that they may not be a good representation of the general population. This may cause the data to be biased in some way.

Table 3.2 Representation of Students

	Interview EPI	Interview EPII	EPI Spring '00	EPII Fall '00	EPI Fall '00	EPII Spring '01
Total	34	25	149	126	283	236
Women	29 %	20 %	10%*	10%*	16%*	15%*
Minorities	6 %	0 %	**	**	**	**
Withdraw	3 %	0 %	4 %	3%	5 %	2 %
Fail: D&F	24 %	24 %	15 %	16 %	18 %	9 %
Grade of A	24 %	32 %	27 %	22 %	23 %	30 %

* Percentage determined by identifying names on the class rosters. According to the Fall 2001 demographic statistics provided by the Kansas State University Registrar, approximately 14% of sophomore engineering majors are women.

** No data for the number of minorities enrolled is available, however, according to the Fall 2001 demographic statistics provided by the Kansas State University Registrar, approximately 10% of sophomore engineering majors are self-reported minorities.

3.4 *Instructor Interviews*

To determine instructor perceptions of Studio, the interview format seemed to be most logical. Faculty, in particular, are more willing to talk for a few minutes than they are to complete a questionnaire.   Therefore, each faculty member and teaching assistant involved in teaching Studio was interviewed three times during the semester – near the beginning of the semester, about midway through the semester, and after the last class. By interviewing them three times during the semester, their opinions, as the course progressed, could be ascertained. Instructor interviews, like student interviews, were conducted in a semi-structured format with a predetermined a set of questions but also allowing them to ramble as needed. The questions were similar for each round of interviews with minor variations. At the first interview, each instructor was asked what his/her expectations for the course were. They were then asked what aspects of Studio they felt were positive and what were negative. At the third interview, in addition to asking what was positive and negative about Studio, the instructors were reminded of what they had indicated were their expectations at the beginning of the semester and asked if these expectations had been met. They were also asked what they would do differently or the same if they would be teaching Studio the following semester and what advice they would give their colleagues teaching Studio for the first time. Instructor interview protocols are located in Appendix E. Interviews were tape-recorded if the instructor granted permission. (This researcher was also an instructor in Studio and is, thus, not included in the interview data.)

3.5 *Exam Tally*

Part way through the first semester of implementation, the lecturer began having self-doubts. He noted that student performance on exams had improved as compared to when he had last lectured for the course, between 1989 and 1995. However, he was concerned that the improvement was a result of easier exams rather than an overall increase in student understanding of physics. Twenty to thirty percent of his current exams were no longer direct “plug-and-chug” problem solving questions but rather related to specific conceptual ideas addressed in the course. Consequently, he decided to give the students an exam he had given during the fall of 1989 and make a more direct comparison. Two-thirds of the content of the old exam overlapped with the content of the up-coming exam and so those four problems were used as the problem-solving portion of the exam. Since only the exam average from the 1989 exam was known, an exact comparison was impossible, however, by tallying student scores for the overlapping problems of the exam the Development Team decided that a comparison of performance on problem-solving could be made. The tally was done by recording each individual student's score for each question part for the exam and then finding the average for each part. After doing this tally for one exam we realized that tallying all the parts of the exam scores for all the exams could give an idea of student understanding of concepts as expressed/expected by instructor exam questions. Consequently, the remaining exams of the semester were tallied as well as all of the exams given by the same lecturer for the following two semesters.

Chapter Four: Data and Analysis

In order to undertake this investigation, several methods of data collection were used. Written, multiple-choice conceptual surveys – pre- and post-instruction – measured student conceptual gains. Written exit surveys ascertained student opinions and attitudes related to the course in its new structure. Multiple interviews of student volunteers tracked student perceptions of the course throughout the two semesters. Multiple interviews of the faculty and teaching assistants tracked instructor perceptions of the course. Finally, averages of individual questions on exams given by the primary faculty member were tallied. With the exception of one of the conceptual surveys administered to a traditionally taught course, all data were collected during the first three semesters Studio was implemented. All of these methods of data collection provide different viewpoints into the fabric of the Engineering Physics course.

4.1 *Written Surveys: Concepts*

Two different conceptual surveys were given to all students enrolled in the Engineering Physics courses: the Force Concept Inventory (FCI) and a conglomerate survey referred to as the Engineering Physics II Conceptual Survey (EPIICS). The FCI was administered to the Engineering Physics I course in its traditional format one year prior to implementing the Studio format and for three semesters after implementation. The EPIICS was not developed until just prior to the implementation of the Studio format and was thus only administered to the students enrolled in the Studio course for the two semesters following implementation.

4.1.1 *The Force Concept Inventory*

The Force Concept Inventory was administered to all students enrolled in Engineering Physics I for the first three semesters the course was taught in the Studio format. The survey was given in Studio during the first or second Studio meeting for the pre-test and approximately one week after instruction of Newton's Laws was completed for the post-test. Prior to changing to the Studio format, the FCI was administered in the laboratory sections, pre- and post-instruction, to the students enrolled in Engineering Physics I during the Spring of 1999. All students were given the option of not participating in the survey, however, very few opted to not participate. The data collected have been analyzed in several ways. First, three different statistical analyses – fractional gains, effect size, and t-test – were calculated for each semester. Then, the data from the traditional format semester were compared to each semester's data using a t-test. Finally, the correlations between pre-test and grade, post-test and grade, and difference between pre-and post-tests and grade were evaluated.

As mentioned in Chapter 2, the equation

$$< g >= \frac{(post\% - pre\%)}{(100\% - pre\%)} \tag{4.1}$$

is used to calculate fractional gains where <g> is the fractional gain, post% is the percent score on the post-test, and pre% is the percent score on the pre-test. Thus, the difference in score is normalized by the maximum possible gain. This method of evaluation, which has been used extensively by the Physics Education Research community, was introduced by Richard Hake when he made a large scale comparison of conceptual understanding gains between interactive-engagement and traditional methods of teaching physics. Hake defines a high gain to be greater than or equal to 0.7, medium gain to be less than 0.7 and greater than or equal to 0.3, and low gain to be less than 0.3. On average, Hake found that traditional courses tended to have low gain while interactive-engagement courses tended to have medium gain (Hake 1998). The fractional gain of the Spring 1999 traditional course was 0.17±0.90 while the fractional gains of the Spring 2000, Fall 2000, and Spring 2001 Studio courses were 0.42±0.31, 0.41±0.25, and 0.39±0.26 respectively. Thus, not only does the Studio format appear to improve student conceptual understanding when compared to the traditional format, its results are in agreement with Hake's data.

The effect size normalizes the difference in score by the standard deviation and is calculated using the equation

$$ES = \frac{< post > - < pre >}{s} \tag{4.2}$$

where <post> is the mean value of the post-test score, <pre> is the mean value of the pre-test score, and s is the standard deviation of the difference between the pre-test scores and the post-test scores. An effect size of 1.5, for example, indicates that scores improved by 1.5 standard deviations. Although there is some disagreement, usually, an effect size greater than 0.8 is considered to be large and greater than 0.5 to be medium (Hinkle, Wiersma, & Jurs 1998). By analyzing the data reported by Hake (1998), we determined that a typical effect size for an interactive-engagement course is 1.7 to 2.3 while the effect size for a traditional course is about 0.5. The effect size for the Kansas State traditional course taught during the Spring of 1999 was 0.46 while the effect size of the Spring 2000, Fall 2000, and Spring 2001 Studio courses were 1.53, 1.71, and 1.59 respectively. This result is very close to the effect sizes determined from Hake's data.

A t-test is a standard statistical test used to compare the mean values of two measurements and is calculated using the equation

$$t = \frac{(\overline{X}_1 - \overline{X}_2) - (\mu_1 - \mu_2)}{s_{\overline{X}_1 - \overline{X}_2}} \tag{4.3}$$

where $\overline{X}_1$ is the mean value of the first measurement, $\overline{X}_2$ is the mean value of the second measurement, and μ_1 and μ_2 are the hypothesized values and considered to be equal. The value $s_{\overline{X}_1 - \overline{X}_2}$ is the standard error computed by the equation

$$s_{\overline{X}_1 - \overline{X}_2} = \sqrt{s_{\bar{x}_1}^2 + s_{\bar{x}_2}^2} \tag{4.4}$$

where $s_{\overline{X}_1}$ is the standard error of the first measurement and $s_{\overline{X}_2}$ is the standard error of the second measurement. This standard error calculation is used because the standard deviations of the two measurements are not equal. To determine if there is a significant difference between the two means, the value of the t-test must be greater than the critical value. The critical value is determined by using a table which relates the degrees of freedom for the measurement and the level of significance. The degrees of freedom are computed using the equation

$$df = \frac{\left(s_{\bar{x}_1}^2 + s_{\bar{x}_2}^2\right)^2}{\left(\left(s_{\bar{x}_1}^2\right)^2/(n_1 - 1)\right) + \left(\left(s_{\bar{x}_2}^2\right)^2/(n_2 - 1)\right)} \qquad (4.5)$$

where n_1 is the number of subjects in the first measurement and n_2 is the number of subjects in the second measurement. For a two-tailed test with the level of significance of 0.10 and the degrees of freedom higher than 120, the critical value of the t-test is 1.645 (Hinkle, Wiersma, & Jurs 1998).

The t-test was used to make two different comparisons. The first comparison was to determine if there was a significant difference between the pre-test scores and post-test scores for each semester the FCI was given. For this comparison, SPSS Base 10.0 statistical package was used. For the Spring 1999 traditional course, t = 4.64. For the Spring 2000, Fall 2000, and Spring 2001 Studio courses, t = 16.73, 26.44, and 15.21 respectively. All are significant. This indicates that, even in the traditional course, students were making significant gains. The second comparison was to determine if there was a significant difference between the traditional course and each of the interactive-engagement courses. Due to complications with SPSS, these calculations were done using a Microsoft Excel spreadsheet. For the Spring 2000 course t = 5.804, for the Fall 2000 course t = 6.600, and for the Spring 2001 course t = 5.453. This indicates that students have made significant gains in the interactive-engagement courses as compared to the traditional course. A summary of the fractional gain, the effect size and the t-test scores for the individual courses is shown in Table 4.1. The final column in the table indicates that one instructor taught the lecture component of the traditional course while two other instructors were involved in the lecture component of the Studio courses. Table 4.2 summarizes the t-test between the traditional course and the interactive-engagement courses.

Table 4.1 Pre vs. Post Summary Chart for the Force Concept Inventory

Course	Fractional Gain	Effect Size	t-test $t_{cv} = 1.645$	Instructor
Traditional Spring 1999	0.17 ± 0.90	0.46	4.64	A
Studio Spring 2000	0.42 ± 0.31	1.53	16.73	B
Studio Fall 2000	0.41 ± 0.25	1.71	26.44	C
Studio Spring 2001	0.39 ± 0.26	1.59	15.21	B

Table 4.2 Traditional vs. Studio for the Force Concept Inventory

Traditional	Studio	t-test $t_{cv} = 1.645$
Spring 1999	Spring 2000	5.804
Spring 1999	Fall 2000	6.600
Spring 1999	Spring 2001	5.453

In addition to determining whether or not the gains students had made on the Force Concept Inventory were statistically significant, I wanted to see if there was any correlation between the course grades students earned and their pre-test scores, their post-test scores and the difference between their pre- and post- test scores. A Pearson product-moment correlation coefficient, or Pearson's r, is a number which indicates how well two measurements are related. Usually, if $0.0 < r < 0.3$ there is no correlation, if $0.3 < r < 0.5$ there is low correlation, if $0.5 < r < 0.7$ there is moderate correlation, if $0.7 < r < 0.9$ there is high correlation, and if $0.9 < r < 1.0$ there is very high correlation. Pearson's r is calculated using the equation

$$r_{XY} = \frac{\sum z_X z_Y}{n-1} \tag{4.6}$$

where n is the number of subjects and z_X and z_Y are the standard scores. Standard scores are calculated using the equation

$$z = \frac{X - \overline{X}}{s} \tag{4.7}$$

where X is the raw score of an individual subject, $\overline{X}$ is the mean score of the measurement and s is the standard deviation of the measurement (Hinkle, Wiersma, & Jurs 1998). The Pearson's r was calculated using SPSS and is tabulated in Table 4.3.

Table 4.3 Summary of Pearson's r Correlations for the Force Concept Inventory

Course	Pre vs. Grade	Post vs. Grade	Difference vs. Grade	Instructor
Traditional Spring 1999	0.15	0.43	0.28	A
Studio Spring 2000	0.34	0.68	0.25	B
Studio Fall 2000	0.21	0.39	0.22	C
Studio Spring 2001	0.12	0.32	0.10	B

From the table it is easy to see that there is little to no correlation between the pre-test scores and the course grades. This is expected as, hopefully, what conceptual understanding the students have when they begin the course is not related to their final course grade. That there is low to moderate correlation between post-test scores and course grades is also expected as the course grades are based primarily on components of the course other than conceptual understanding. Thus, other aspects, such has problem solving skills, will have influenced their final course grades. It is interesting to note that for the first semester that Studio was taught, the correlation between the post-test and the course grades was much stronger than any other semester. Finally, there is little to no correlation between the difference in pre- and post-test scores and course grades. This indicates that the amount of conceptual gains students have made have little bearing on their final course grades.

4.1.2 *The Engineering Physics II Conceptual Survey*

Due to time constraints, the Engineering Physics II Conceptual Survey (EPIICS) was not developed until August 2000, just prior to the implementation of the Engineering Physics II course in the Studio format. Without data from the traditional format, the analysis is more limited than that of the FCI. The three different statistical analyses – fractional gain, effect size, and t-test – were done for the two semesters of data collected as well as examining the correlations between pre-test and grade, post-test and grade, and difference between pre-and post-tests and grade.

While the computation of fractional gains was developed for the FCI it seemed reasonable to apply the same techniques and criteria to the EPIICS. During the first semester of implementation in the Fall of 2000, the students made fractional gains of 0.42±0.21 and during the Spring 2001 semester they made gains of 0.29±0.19. Both of these are on the low end of what is considered to be medium gain. This seems reasonable considering the more abstract nature of the Engineering Physics II course as compared to the Engineering Physics I course. The effect sizes of the two semesters were 2.00 and 1.47 respectively. Again, external data is not available for comparison, however, these results fall within the range of interactive-engagement as determined from Hake's analysis of the FCI data. Finally, the t-test scores for the two semesters are 21.09 and 19.09 which indicate that the gain students made was significant. A summary of the fractional gain, the effect size and the t-test scores for the individual courses, with two different lecturers, is shown in Table 4.4.

Table 4.4 Pre vs. Post Summary Chart for the Engineering Physics II Conceptual Survey

Course	Fractional Gain	Effect Size	t-test $t_{cv} = 1.645$	Instructor
Fall 2000	0.42 ± 0.21	2.00	21.09	B
Spring 2001	0.29 ± 0.19	1.47	19.09	C

The correlation between student course grades and their pre-test scores, their post-test scores, and the difference between their pre- and post-test scores were also calculated using SPSS. The results are shown below in Table 4.5.

Table 4.5 Summary of Pearson's r Correlations for the Engineering Physics II Conceptual Survey

Course	Pre vs. Grade	Post vs. Grade	Difference vs. Grade	Instructor
Fall 2000	0.22	0.57	0.42	B
Spring 2001	-0.04	0.30	0.32	C

Again, the data indicate little to no correlation between the conceptual understanding a student has coming into the course, as illustrated by their pre-test scores, and final course grades. As with the FCI, their post-test scores are low to moderately correlated with their course grades. The data do indicate that the students who were enrolled in Engineering Physics the first time it was taught in the Studio format had the strongest correlation between post-test scores and course grades on both the FCI and the EPIICS. This result could be a reflection of the students themselves, or how that particular lecture instructor ran the course. The students who take Engineering Physics off-sequence (Spring and Fall) instead of on-sequence (Fall and Spring) are typically moving more rapidly through the engineering curricula and consequently may be more mature than their on-sequence counterparts. The lecturer for the off-sequence course was the faculty member intimately involved in the development of the course and thus, his approach would be more closely matched to the new design of the course. As the same result is not evident in the FCI results during the second time this lecturer was involved with the course, I am inclined to attribute the strong difference to the students and the fact it was the first time the Studio format was used. Unlike the lack of correlation on the FCI, a low correlation exists between the difference between pre- and post-test scores and the course grades. It is possible that, due to the more abstract nature of Engineering Physics II, the amount of conceptual knowledge that students gain is somewhat related to how they perform, overall, in the course. The concepts of electricity and magnetism are not as concrete and visual as the concepts of blocks on a plane are in kinematics, and thus, to do well in Engineering Physics II, students may need to have a better grasp of the concepts than they do in Engineering Physics I.

4.2 *Written Surveys: Opinions*

The written surveys given at the end of the semester for the first three semesters after Studio was implemented, and thus often referred to as the "exit surveys," had two components – open-ended questions and Likert scale questions. During the first semester Studio was implemented only Engineering Physics I was taught in the Studio format. Therefore, five sets of surveys were analyzed.

4.2.1 *Open-ended Questions*

For the first two semesters during which the exit surveys were given, students were asked seven open-ended questions about what they liked and disliked about studio and working in groups as well as what they would change or keep the same about the course. For the third semester, an eighth question was added concerning the helpfulness of the three instructors – faculty member, teaching assistant, and class assistant – involved in each of the studio sections. This question was added primarily for administrative purposes at the request of the department head and was not analyzed. In analyzing the open-ended questions, I went through all exit surveys by course and by question. For each question, I wrote down the individual comments and either binned them into categories of similar ideas or left them as individual comments if they were singular in thought. I then determined which of the categories were comments made by at least ten percent of the students in that course. The choice of ten percent was based on the return ratio normally expected form mailed surveys. Table 4.6 lists the course and number of students who completed the survey. Several of the categories were common throughout the five courses while others were more specific to a particular course or semester. In a few instances I have selected categories in which there was under a ten percent response. These were usually cases where the category was common across all courses. The students enrolled second semester course tended to have more individualistic comments in that there were a wide variety of comments, particularly in the negative questions, but only one or two students made them. I suspect this is, in part at least, due to the students becoming more comfortable with the overall structure of the course and thus are finding smaller details as irritants, or pleasures, to be mentioned.

Table 4.6 Exit Survey Completion by Course

Course (abbreviation)	Completed	10%
Engineering Physics I Spring 2000 (EPI S00)	112	11
Engineering Physics II Fall 2000 (EPII F00)	104	10
Engineering Physics I Fall 2000 (EPI F00)	226	23
Engineering Physics II Spring 2001 (EPII S01)	192	19
Engineering Physics I Spring 2001 (EPI 01)	96	10

The questions and most frequent responses are listed below. Within each question, the responses which were given by ten percent or more of the students in each of the five courses are listed first.

What did you like about Studio?

- Hands-on nature of studio (all)
- Homework problems solved on the board (all)
- Integration and/or incorporation of the laboratory experiments with going over the homework (all except EPII S01)
- Laboratory experiments (all except EPI S00)
- Working in small groups (EPII F00, EPI F00 and EPII S01)
- Experimenting with concepts talked about in lecture (EPII F00 and EPII S01)
- Opportunity for one-on-one interaction with instructors (EPII F00 and EPI F00)
- No formal lab write-ups to be written outside of class (EPI S00 and EPII F00)
- Laid back, informal atmosphere of the classroom (EPI S00)
- Able to get help with questions they might have (EPI S00)
- Labs were helpful in learning the material and understanding the concepts (EPI F00)
- Did not like anything about Studio or left space blank (EPII S01)

What did you dislike about Studio?

- Did not dislike anything about Studio or left space blank (all)
- Individual Studio sessions seemed too long at times (all except EPI F00)
- Felt rushed to finish experiments and/or homework sessions at times (all except EPII S01)
- Some of the labs were pointless or unhelpful (EPI F00, EPII S01, and EPI S01)
- Some of the labs were poorly planned or badly worded (EPI F00, EPII S01, and EPI S01)
- The grading was unfair at times (EPII F00)
- The homework was due the day after it was assigned (EPII F00)
- The instructors were incompetent or hindered due to low language skills (EPII S01)
- Being quizzed over material that was not learned or was too hard (EPII S01)

What did you like about working in groups?

- Everyone brought new ideas and opinions to the table (all)
- Getting to meet new people and make new friends (all)
- Learning from peers (all)
- Somebody at the table could usually figure out how to do the lab or homework (all except EPI S01)
- Partners helped when a member had questions (EPII F00, EPII S01, EPI S01)
- Helped learn cooperation and communication skills (EPI S00, EPII F00, and EPI F00)
- Easier to work out problems and to learn (EPI S01)

What did you dislike about working in groups?

- Did not dislike anything about Studio or left space blank (all)
- Unequal effort given by members of the group (all)
- Some people are easier to work with than others (all)
- Some group members are stupid or slow to grasp concepts (EPI F00, EPII S01, and EPI S01)
- Changing lab groups every few weeks (EPII S01)

For next semester, what would you definitely change about the way Studio is taught?

- There is nothing to change or left space blank (all)
- Allow more time for lab work or fewer labs (EPII F00, EPI F00, and EPI S01)
- Devote more time to solving homework problems on the board (EPI S00 and EPI F00)
- Increase the grading point scale (EPI S00)
- Clarify the goals and refine the procedures of the labs (EPII S01)
- Be able to leave Studio early if finished with lab (EPII S01)
- Have competent instructors or able to speak English well (EPI S01)

What would you definitely keep the same about the way Studio is taught?

- Keep everything else (not mentioned in previous question) the same or left space blank (all)
- Going over the homework problems at the board (all except EPII F00)
- The overall structure/setup/format is nice or works well (EPI S00, EPI F00, and EPII S01)
- Working in small groups (EPI F00, EPII S01, and EPI S01)
- Some experiments are good (EPII F00 and EPI S01)
- The instructors or the number of instructors (EPI F00 and EPI S01)
- Incorporating the homework with the labs (EPII F00)

Suppose you have a friend who is taking Engineering Physics next semester. What advice would you give this friend?

- Study like crazy! (all)
- Understand and do all the homework (all)
- Go to class/studio/lecture (all)
- Don't fall behind (all)
- Comments that relate to having "good" study habits (EPI S00, EPI F00, EPI S01)
- Take advantage of all available resources (EPI F00, EPII S01, and EPI S01)
- Take the course with Dr. Sorensen as the lecturer (EPI S00 and EPI S01)
- Get a good Studio instructor (EPII S01)
- Ask for help if you don't understand (EPI S00)
- Left the space blank (EPII S01)

4.2.2 *Likert Scale Questions*

For the first two semesters that the exit surveys were given, students were asked eight Likert Scale questions. The questions were in the form of statements which the students ranked from "strongly disagree" to "strongly agree." The statements related to their perception of the connections among components of the course, their satisfaction with physical aspects of the course, and their perceptions of how the course related to their learning of physics. The rankings were converted into numerical form where 1 is "strongly disagree" and 5 is "strongly agree" and tabulated for each course (see Tables 4.7, 4.8, and 4.9).

Table 4.7 Exit Survey Data for Engineering Physics I Spring 2000

Connections between homework and lab were clear	3.88 ± 0.86
Connections between lab and lecture were clear	4.01 ± 0.78
Connections between lecture and homework were clear	3.81 ± 0.91
Satisfied with level of use of computers	3.93 ± 0.76
Satisfied with physical arrangement of room	3.82 ± 0.97
Satisfied with amount of interaction with instructors	4.09 ± 0.87
There is more to physics than problem solving	4.27 ± 0.82
Integration of problem solving and lab helped me learn physics	4.11 ± 0.83

Overall, during the first semester of implementation, the students agreed with the eight statements. They felt that connections between the homework, laboratory and lecture components of the course were clear and apparent. They were satisfied with the amount that computers were used in the Studio as well as the physical room arrangement. In addition, they were satisfied with the amount of interaction they had with the instructors and felt the integration of homework with laboratory work helped them learn physics. Finally, they agreed with the statement that there is more to physics than solving problems.

Table 4.8 Exit Survey Data from Engineering Physics II Fall 2000

Connections between homework and lab were clear	3.76 ± 0.86
Connections between lab and lecture were clear	4.01 ± 0.84
Connections between lecture and homework were clear	3.53 ± 0.97
Satisfied with level of use of computers	3.67 ± 0.71
Satisfied with physical arrangement of room	3.44 ± 1.02
Satisfied with amount of interaction with instructors	3.93 ± 0.88
There is more to physics than problem solving	4.13 ± 0.87
Integration of problem solving and lab helped me learn physics	4.07 ± 0.72

Approximately the same students were enrolled in the second semester course in the Fall of 2000. Overall, they still agreed with the statements although they did become slightly more neutral on all of them except for the connections between laboratory and lecture where the average was exactly the same. This decrease in agreement is to be expected as the students have become more accustomed to the course in the Studio format and are less apt to be forgiving of details. One interesting factor is that, during the first year, the Studio component of the second semester course was taught in a traditional laboratory classroom as the Studio classroom had not yet been remodeled. Despite this change from a room conducive to interaction to a less conducive room the students still remained more than neutrally satisfied with the physical arrangement of the room. Since most of the students were aware that the Studio classroom was in the process of being renovated, they were, perhaps, tolerant of the temporary situation.

Table 4.9 Exit Survey Data from Engineering Physics I Fall 2000

Connections between homework and lab were clear	3.71 ± 0.88
Connections between lab and lecture were clear	3.72 ± 0.87
Connections between lecture and homework were clear	4.08 ± 0.78
Satisfied with level of use of computers	3.90 ± 0.79
Satisfied with physical arrangement of room	3.78 ± 0.84
Satisfied with amount of interaction with instructors	3.87 ± 0.82
There is more to physics than problem solving	3.92 ± 0.69
Integration of problem solving and lab helped me learn physics	3.76 ± 0.88

The students who enrolled in the first semester Studio course during the second time that it was taught in the interactive-engagement format were also in agreement with the eight statements. However, they were less in agreement than their counterparts from the previous semester. Three factors may have contributed to this situation. First, the newness of the course may have been wearing off and the students were settling into a steady state of satisfaction. Second, students who take Engineering Physics off-sequence instead of on-sequence may be more mature than their on-sequence counterparts. Finally, during the Fall of 2000 the lecture portion of the course was taught by a faculty member who was not intimately involved in the development of the course. His expectations for the course, while similar to the primary developer, may have influenced the students.

For the third semester of implementation, the Likert statements were changed to reflect some changes that were made to the course. Since the physical arrangement of the room was not to be altered again, that statement was removed from the survey. Three statements about interaction between the groups and the three studio instructors in each sections were added. In addition, two statements were added concerning with which of the three instructors students were most comfortable interacting for questions on homework or the lab. These five statements were added for departmental administrative purposes. The seven Likert scale statements which were carried over from the previous exit surveys are tabulated in Tables 4.10 and 4.11.

Table 4.10 Exit Survey Data from Engineering Physics II Spring 2001 – Original Questions

Connections between homework and lab were clear	3.45 ± 0.94
Connections between lab and lecture were clear	3.64 ± 0.87
Connections between lecture and homework were clear	3.87 ± 0.85
Satisfied with level of use of computers	3.68 ± 0.77
Satisfied with amount of interaction with instructors	3.74 ± 0.73
There is more to physics than problem solving	3.76 ± 0.90
Integration of problem solving and lab helped me learn physics	3.54 ± 0.88

The students enrolled in the second semester course during the Spring of 2001 were approximately the same students as those enrolled in the first semester course the previous semester. As with their counterparts in the previous cycle, their agreement with the statements was slightly more neutral than their agreement the first semester.

Table 4.11 Exit Survey Data from Engineering Physics I Spring 2001 – Original Questions

Connections between homework and lab were clear	3.76 ± 0.78
Connections between lab and lecture were clear	3.94 ± 0.82
Connections between lecture and homework were clear	3.80 ± 0.87
Satisfied with level of use of computers	3.81 ± 0.98
Satisfied with amount of interaction with instructors	3.88 ± 0.82
There is more to physics than problem solving	4.15 ± 0.78
Integration of problem solving and lab helped me learn physics	3.95 ± 0.81

The students enrolled in the first semester course during the Spring of 2001 were starting the third cycle of Studio. Their lecture instructor was, once again, the faculty member intimately involved in the development of the course. Overall, these students also agreed with the statements and responded at approximately the same level as the students from the previous spring.

The three statements added to the Spring 2001 exit survey pertaining to how often groups interacted with the Class Assistant, the Teaching Assistant, and the Faculty Member were rated from never to always. For these statements, the numbers are based on a scale of 1 to 5 where 1 is never and 5 is always. Tables 4.12 and 4.13 tabulate the new questions for the two courses.

Table 4.12 Exit Survey Data from Engineering Physics II Spring 2001 – Group interaction with Instructors

Interaction between Class Assistant and group	2.80 ± 1.09
Interaction between Teaching Assistant and group	3.72 ± 0.79
Interaction between Faculty Member and group	2.77 ± 1.02

Table 4.13 Exit Survey Data from Engineering Physics I Spring 2001 – Group Interaction with Instructors

Interaction between Class Assistant and group	2.76 ± 0.92
Interaction between Teaching Assistant and group	3.71 ± 0.77
Interaction between Faculty Member and group	2.98 ± 1.00

The students enrolled in both courses indicated that, as a group, they often interacted with the Teaching Assistants but only sometimes interacted with the Class Assistant and Faculty member. This could be for a variety of reasons. All three members of the teaching staff were to be equally able to assist students as they worked on the laboratory activities. However, the faculty were not required to stay in the Studio classroom the entire time and would, therefore, sometimes not be available to the students. Also, as the Teaching Assistants had the sole responsibility of grading the assignments, students may have sought more interaction with them for confirmation of what they had completed for a grade.

The final two statements in the Likert scale section of the exit surveys were not actually based on a Likert scale. The students were to choose with which of the three instructors in their studio section they were most comfortable interacting for homework problems and experiments. Many students did not choose only one and, thus the categories are varied. In Tables 4.14 and 4.15 the percentage of students in the course who chose a category are indicated. A few students did not indicate anything and could be considered to be in the "none" category. However, I am distinguishing between those who indicated none as opposed to those who did not answer the question. Thus, the percentages do not necessarily equal 100. For both courses, the students indicated they were more comfortable interacting with the Faculty Member on the homework and the Teaching Assistant on the experiments. This is to be expected as the Faculty Member, almost exclusively, would answer homework questions in front of the class in a "recitation" format while the Teaching Assistant would be in charge of the experimentation. Also, in many cases, the Faculty Member would not be present during all, or part, of the time spent in Studio on experimentation.

Table 4.14 Exit Survey Data from Engineering Physics II Spring 2001 – Comfort Level

Category	Homework	Experiment
Class Assistant	9.4	17.2
Class Assistant and Teaching Assistant	4.2	10.4
Teaching Assistant	32.3	58.3
Teaching Assistant and Faculty Member	6.8	4.7
Faculty Member	41.7	8.3
Faculty Member and Class Assistant	0.5	0
All	1.0	0
None	2.6	0
Students	0.5	0

Table 4.15 Exit Survey Data from Engineering Physics I Spring 2001 – Comfort Level

Category	Homework	Experiment
Class Assistant	0	4.2
Class Assistant and Teaching Assistant	2.1	5.2
Teaching Assistant	34.4	66.7
Teaching Assistant and Faculty Member	6.3	3.1
Faculty Member	50.0	15.6
Faculty Member and Class Assistant	0	0
All	3.1	2.1
None	3.1	0
Students	1.0	0

4.3 *Student Interviews*

At the beginning of the first and second semesters of implementation students were asked to volunteer to be interviewed periodically throughout the semester for two semesters. Two categories of students were sought: new to Engineering Physics and previously taken Engineering Physics in the traditional format. The purpose of the interviews was to ascertain student perceptions of course content and structure as the course progressed. The interviews were also to ascertain how students approached the exams as the course progressed. That is, did they view the questions on the exams as ones for which they were to plug numbers into memorized equations or as questions about concepts or ideas that they can apply to any situation? Over the course of the three semesters, 41 students were interviewed a total of 284 times. For the purposes of this study, I decided that 284 interviews were too many to analyze and so reduced the number to 125 interviews. To do this, I first eliminated all students who came for fewer than four interviews and two students who did not complete the course. Of the remaining women, I kept the one who had taken Engineering Physics I in the traditional format and retook it in the Studio format. Four additional women were involved in the first implementation of the course. Of these four, two interviewed both semesters and two interviewed for only the first semester. I arbitrarily chose one of each. For the three women involved in second implementation of the course, I kept the one who only interviewed for the first semester and arbitrarily chose one of the two who interviewed both semesters. For the men who were retaking the course, I kept everyone who completed the course and also completed the second semester. I also arbitrarily kept one of the three men who only interviewed the first semester. For the second semester course, I kept one of the two students who took Engineering Physics in the traditional format and retook in the Studio format. I kept in the study the one male student who took Engineering Physics I in the traditional format and Engineering Physics II in the studio format but eliminated the one who had taken the equivalent of Engineering Physics I at a different institution. For the male students involved in the first implementation of the course, I now had a fairly large selection of interviewees whose grades had been average to poor. I thus reduced the number to those who had earned an "A" in both courses and had an unsuspecting colleague chose one. For the remaining male students who were involved in the second implementation of the course, I had the same colleague chose one. Of all of the volunteers, only two were minority students. Both were involved in the course during the first implementation and did not take the second semester course. Both were included in the study. Finally, three of the original volunteers failed Engineering Physics I in the studio format and retook the course. Two of these students had taken Engineering Physics I in the traditional format and were already included in the study. The third, thus, was also retained.

To analyze the interviews, I utilized a similar method to that which I had used with the open-ended questions on the exit surveys. While reading through my notes of the interviews, I focused on what was said for six main topics: influences, likes, dislikes, distracters, changes, and groups. In every interview, except for the interviews with the three students retaking Studio, students were asked what influenced them while they were taking the exams as well as what about the course distracted them from learning what they would like to. The remaining topics were only addressed in the first, third and fifth interview of a semester. This approach will affect the overall percentage of responses. The students retaking Studio were not specifically asked their likes and dislikes of Studio, however, the comments they made, except for those specific to their retaking Studio, tended to fall into these categories. I also kept track of general comments that were made that didn't necessarily fall into the six categories as well as answers to questions which were asked once or to a particular group of interviewees. If an aspect of the course, in any category, was mentioned by approximately 10 percent of a group, I have included it in my discussion.

For analysis purposes, the students were also divided into six categories: women, women retaking Engineering Physics, students retaking Studio, men retaking Engineering Physics, men, and minorities. For the students retaking Studio, only the interviews done while they were retaking Studio were included in the category. In addition, for the men retaking Engineering Physics I who continued with the interviews while enrolled in Engineering Physics II, their interviews while they were retaking were included in the "retaking" category while their remaining interviews were included in the "men" category. In discussion, however, only four categories will be included: women, students retaking Engineering Physics, students retaking Studio, and men. The retaking students are also included in their respective gender categories. Table 4.16 shows the number of interviews in each category. Due to their small numbers, no conclusive ideas can be drawn from the minorities on their own, and so they are grouped with the men.

Table 4.16 Number of Interviews per Category

Category	Number of Interviews
Women	34
Retakers	30
Men	83
Studio Retakers	8
Overall	125

A variety of aspects influenced the students while they were working on the exam. These included the homework, the lectures, the review sessions prior to the exam, Studio in general, a specific lab, and the sample quiz or previous quiz provided by the instructor. Table 4.17 shows these aspects and the percentage of students, by category, who mentioned them. Many students mentioned more than one influencing factor. The students retaking Studio were not asked this question and are not included.

Table 4.17 Influencing Factors on Exams by Category

Influences	Women	Retakers	Men	Overall
Lectures	32%	13%	29%	30%
Homework	50%	17%	19%	28%
Review Sessions	3%	3%	12%	9%
Studio	0%	17%	13%	9%
Lab	18%	7%	4%	8%
Sample Quiz	0%	0%	10%	8%

A wide variety of distracters were mentioned by the students. However, the women tended to focus on physical aspects of the course – problems with lab equipment or group members – while the men tended to focus on personal factors – lack of sleep or mental state. Table 4.18 shows these aspects and the percentage of students, by category, who mentioned them. Again, the students retaking Studio were not asked this question and, thus, are not included. The first category – nothing – was only marked if a student specifically stated he/she felt nothing distracted them.

Table 4.18 Distracters by Category

Distracters	Women	Retakers	Men	Overall
Nothing	24%	17%	29%	27%
Other classes	9%	17%	16%	14%
Me – time management	0%	0%	13%	9%
Too much information too fast	12%	7%	6%	8%
Lack of interest/motivation	0%	10%	8%	7%
Lab partners	15%	13%	2%	6%
Not enough sleep	0%	10%	6%	4%

The students all had different aspects of Studio which they liked. While there were no overall prevailing aspects the students liked, what they mentioned agreed with the responses given by their classmates on the exit survey.

Table 4.19 Likes by Category

Likes	Women	Retakers	Men	Studio Retakers	Overall
Combining homework and lab	24%	23%	14%	0%	16%
Like in general/overall	15%	17%	14%	25%	15%
Going over homework	15%	17%	17%	0%	15%
No outside lab reports	9%	23%	13%	13%	12%
Informal atmosphere	3%	20%	12%	0%	9%
The labs (or a specific lab)	12%	7%	8%	0%	9%
Changing groups	3%	3%	8%	38%	9%

While the students mentioned several changes which they felt could improve the Studio, they only mentioned one overwhelming dislike. Instead, the students tended hedge the question by either not really giving an answer, or mentioning something which could be an improvement. Table 4.20 shows the one dislike mentioned and Table 4.21 shows the changes the students felt could be an improvement.

Table 4.20 Dislikes by Category

Dislikes	Women	Retakers	Men	Studio Retakers	Overall
Not enough time to complete all activities and homework in class	3%	23%	25%	13%	18%

Table 4.21 Changes Which Could Improve Studio by Category

Changes	Women	Retakers	Men	Overall
Need more class periods: lecture and/or Studio	0%	17%	17%	11%
Improve the lab manual	15%	10%	5%	7%
Focus more on problem solving and less on Studio (labs)	3%	10%	8%	6%
Have weekly review/help sessions*	15%	0%	0%	4%
Use the web site to post exams, solutions, etc.*	0%	10%	5%	3%
Change the grading scale**	9%	7%	1%	3%
Need more people helping in Studio**	3%	13%	4%	3%

* One of the instructors does not do this while the other does
** Aspects which did change after the first semester of implementation

Very few comments were made about working in groups. Of the eight aspects that were mentioned, only three were negative and two were made only by students retaking Engineering Physics. Again, all of the aspects mentioned were also expressed on the exit surveys.

Table 4.22 Comments on Groups by Category

Likes	Women	Retakers	Men	Studio Retakers	Overall
Learning from peers	29%	23%	31%	13%	30%
Like in gnereal	3%	17%	17%	0%	12%
Some students not interested in doing the labs	9%	3%	4%	13%	6%
Four is too many	3%	13%	4%	0%	3%

There were several questions which I specifically asked a particular group of students. During the first semester of implementation, the students did a computer simulation as an activity for Kepler’s Law. I asked the interviewees if they thought more simulations should be used in studio. Eight of the eleven said yes while two said no and one did not answer the question. The two negatives were both retaking the course. I also specifically asked the students retaking Studio what they were doing differently the second time through Studio and whether or not taking Studio a second time was helping them master the concepts. Doing more homework was mentioned as a difference five times over the eight interviews. However, of the eight interviews, retaking Studio did not help them master the concepts was mentioned five times. In addition, two general comments and an observation came out that do not fall into any of the above categories. These three aspects are tabulated in Table 4.23. The first comment was that the Studio method is much better than the traditional method, and the second was that doing a computer simulation was mentioned as what could be done in Studio to better help the students understand a particular concept. The observation was how frequently, or infrequently, an activity was specifically mentioned when the students were asked what they were thinking about as they worked on a problem on the exam. While I was not specifically paying attention to what the students mentioned, other than an activity, students tended to either say that they had done a problem in the homework like it, or just started talking about the formulas they used. None of the students retaking Studio were given the opportunity to make these three comments and are not included in the percentages.

Table 4.23 General Observations by Category

Comments	Women	Retakers	Men	Overall
Studio is better than traditional method	6%	40%	14%	12%
Do a computer simulation	0%	7%	11%	8%
A lab in Studio	6%	17%	12%	10%

4.4 *Instructor Interviews*

To determine instructor perceptions of Studio, each faculty member and teaching assistant involved in teaching Studio was interviewed three times – near the beginning of the semester, about midway through the semester, and after the last class. During the Spring of 2001 only instructors teaching Engineering Physics II were interviewed in order to have interviews from instructors of two complete cycles of the course. For this semester, if an instructor had taught Studio previously, he or she was interviewed only at the end of the semester. I had determined during the Fall that the opinions of the instructors who had taught Studio the previous semester did not change significantly over the course of their second semester of teaching and that my welcome was wearing thin.

To evaluate the interviews I utilized an analytical inductive approach where I extracted the major ideas of the participants from the statements of the participants themselves. This approach does not lead to an underlying model or theory but is the first step toward such a theory (LeCompte & Preissle, 1993). I first read through my notes from all of the interviews and wrote down any theme or idea which seemed to be common throughout. These items were called minor categories. I then divided the interviews into “Faculty” and Teaching Assistants” and subdivided by semester and course. On the second time through the interviews, I tallied how often a particular minor category was mentioned by either a Faculty Member or a Teaching Assistant and which semester and course that person was teaching. A few minor categories emerged during this process while a few were eliminated when it turned out they were mentioned only three of four times throughout the interviews. The minor categories seemed to fall into four major categories – Logistics and/or Administration, Pedagogy, Student/Teacher

Attitudes, and Things We Tried To Change – with some overlap. To establish validity of the categorization, I gave the list of minor categories and the four major categories to three independent sources – a member of the Development Team, a post-doctoral student with the Physics Education Research Group at Kansas State, and an external educator unfamiliar with the course – and asked them to bin, to the best of their ability, the minor categories into the major categories. Table 4.24 lists the minor categories and indicates into which major category they seem to fall. As can be seen in the table, every minor category in the fourth major category also falls into at least one of the other categories. This makes sense, as anything we tried to change would be to address an issue in the other categories.

Table 4.24 Minor Categories from Instructor Interviews Binned into Major Categories

Minor Categories	Major Categories			
	1	2	3	4
Changing group members is good	x		x	
Class Assistant responsibilities	x			x
Do the activity first		x		
Do the homework first		x		
Do the lab before teaching Studio		x		
Faculty only staying for one hour not working	x		x	x
Grading load of Teaching Assistants	x			
Grading scale	x			x
Group work		x		
Hands-on		x		
Instructors having fun/enjoying it			x	
Integration/connection of homework and lab – good		x	x	
Integration/connection of homework and lab – lack			x	x
Lack of communication between instructors	x			
More beneficial to student/learning more			x	
More student/teacher interaction			x	
Number of instructors teaching lab	x			x
Problem solving priority/faculty task is to do problems		x	x	
Room size/facilities/atmosphere – bad	x			x
Room size/facilities/atmosphere – good	x			
Separate lab and recitation	x	x	x	
Size of small groups too large		x	x	
Small groups are not working well together		x	x	
Small groups are working well together		x	x	
Some labs are trivial		x	x	x
Students happy/having fun		x	x	
Students were distracted by equipment during recitation time	x			
The professor there is positive			x	
The survival/success of Studio in the department			x	
The time load	x			x
This way (format) is better/good			x	
Time in Studio - Leave early if finished	x			
Time in Studio - Rushed to finish	x		x	x
Tweak lab manual		x		x
Use of computers		x		
Use of office hours - lack		x	x	

Major Categories:
1 = logistics and/or administration
2 = pedagogy
3 = student/teacher attitudes
4 = things we tried to correct

Tables 4.25 through 4.28 separate out the four major categories and indicate if each minor category was important to the Faculty, the Teaching Assistants, or both. The importance was based on how often the idea was mentioned by the Faculty and/or Teaching Assistants. Approximately 39% of the minor categories were logistical or administrative in nature, while approximately 45% were pedagogical and 53% were attitudinal. Finally, approximately 28% of the minor categories were issues we tried to address. Overall, 61% of the minor categories were important to both the faculty and the teaching assistants. Because I chose the categories based on what seemed to be common themes throughout the entire set of instructor interviews, this result is expected. The categories which were only of importance to the faculty tended to be issues which were within their main responsibilities in the Studio classroom – solving homework problems on the board. On the other hand, the categories important only to the teaching assistants centered around their primary responsibilities – the experiments and grading.

Table 4.25 Minor Categories which fell into the Logistics and/or Administration Major Category with indication of importance to Faculty and Teaching Assistants

Minor Categories	Faculty	TA	Both
Changing group members is good		x	
Class Assistant responsibilities		x	
Faculty only staying for one hour not working	x		
Grading load of Teaching Assistants		x	
Grading scale			x
Lack of communication between instructors		x	
Number of instructors teaching lab			x
Room size/facilities/atmosphere – bad	x		
Room size/facilities/atmosphere – good			x
Separate lab and recitation	x		
Students were distracted by equipment during recitation time	x		
The time load			x
Time in Studio - Leave early if finished	x		
Time in Studio - Rushed to finish			x

Table 4.26 Minor Categories which fell into the Pedagogy Major Category with indication of importance to Faculty and Teaching Assistants

Minor Categories	Faculty	TA	Both
Do the activity first	x		
Do the homework first			x
Do the lab before teaching Studio			x
Group work			x
Hands-on		x	
Integration/connection of homework and lab – good			x
Problem solving priority/faculty task is to do problems	x		
Separate lab and recitation	x		
Size of small groups too large	x		
Small groups are not working well together			x
Small groups are working well together	x		
Some labs are trivial			x
Students happy/having fun			x
Tweak lab manual			x
Use of computers			x
Use of office hours - lack			x

Table 4.27 Minor Categories which fell into the Student/Teacher Attitude Major Category with indication of importance to Faculty and Teaching Assistants

Minor Categories	Faculty	TA	Both
Changing group members is good		x	
Faculty only staying for one hour not working	x		
Instructors having fun/enjoying it			x
Integration/connection of homework and lab – good			x
Integration/connection of homework and lab – lack			x
More beneficial to student/learning more			x
More student/teacher interaction			x
Problem solving priority/faculty task is to do problems	x		
Separate lab and recitation	x		
Size of small groups too large	x		
Small groups are not working well together			x
Small groups are working well together	x		
Some labs are trivial			x
Students happy/having fun			x
The professor there is positive			x
The survival/success of Studio in the department			x
This way (format) is better/good			x
Time in Studio - Rushed to finish			x
Use of office hours - lack			x

Table 4.28 Minor Categories which fell into the What We Tried To Change Major Category with indication of importance to Faculty and Teaching Assistants

Minor Categories	Faculty	TA	Both
Class Assistant responsibilities		x	
Faculty only staying for one hour not working	x		
Grading scale			x
Integration/connection of homework and lab – lack			x
Number of instructors teaching lab			x
Room size/facilities/atmosphere – bad	x		
Some labs are trivial			x
The time load			x
Time in Studio - Rushed to finish			x
Tweak lab manual			x

The instructors who were involved in teaching Studio over the three semesters of evaluation varied widely in their classroom experience. The faculty rank ranged from full professor in the field for forty years to first year postdoc. All but one, a postdoc with the Physics Education Research Group, were not automatically sympathetic to ideas of innovative teaching methods. The teaching assistants ranged from upper-level undergraduate students to senior graduate students. Despite these differences, the overall reaction to Studio was positive. The majority of the positive aspects mentioned were pedagogical in nature. They felt that this method of teaching was better than the old, traditional, method. They mentioned the connections that were now being made between the homework and the laboratory activities as well as the interaction students were getting among themselves and with instructors. They were having fun. The majority of the negative aspects were logistical and/or administrative in nature. They felt that their teaching load was too high as compared to the previous one; they felt rushed to finish everything assigned in the time frame available; and they felt a lack of communication. Many of the negative aspects were ones which we tried to change each successive semester. We tried to reduce faculty time in the Studio and lighten the grading load of the teaching assistants, some of the activities in the lab manual were re-written to either shorten them or clarify their goals, and the grading scale was altered.

4.5 *Exam Tally*

Beyond the initial exam comparison, the exam tally was not evaluated. On the initial exam, two-thirds of the content of the 1989 exam overlapped with the content of the third exam during the Spring 2000 semester. Those four problems were used as the problem-solving portion of the exam. Since only the exam average from the 1989 exam was known, an exact comparison was impossible. However, by tallying student scores for the overlapping problems of the exam, the Development Team decided that a comparison of performance on problem-solving could be made. The average score on the Spring 2000 exam and the average score of the four problem solving questions from the 1989 exam were approximately the same – 65%. This result was considerably higher than the approximate 50% average score from the 1989 exam. It belied the lecturer's fears that he was writing easier exams, by indicating that the Spring 2000 students did, indeed, have better problem-solving skills than their 1989 counterparts.

Chapter Five: Results and Conclusions

The purpose of this study was not only to evaluate the learning gains students made when enrolled in an introductory university physics course utilizing an interactive-engagement approach as compared to a traditional approach, but also determine the student and instructor perceptions of that change. To do this task, several methods of data collection and analysis were used. Written, multiple-choice conceptual surveys – pre- and post-instruction – were used to measure student conceptual gains. Written exit surveys were used to ascertain student opinions and attitudes related to the course in its new structure. Multiple interviews of student volunteers tracked student perceptions of the course throughout the semester. Multiple interviews of the faculty and teaching assistants involved tracked instructor perceptions of the course. Finally, averages of individual questions on exams given by the primary faculty member were tallied. All of these methods of data collection and analysis provide different viewpoints into the fabric of the Engineering Physics course.

5.1 *What perceptions do students enrolled in Engineering Physics have of the course in its new format?*

For the most part, the students were positive about the changes that have been made to the course. On the exit surveys, the responses the students made to the "what did you like about studio" question tended to be about the structure and format of the course. They liked the hands-on nature of the course, the integration and/or incorporation of going over the homework with laboratory experiments, the ability to get individual attention in a classroom setting, and the interaction they had with their peers in the form of small groups. The responses for what they disliked about studio or what they would change about studio focused more on the operations of the course, on small details, or on irritants. For, example, they felt rushed to finish and wanted more time to complete labs or go over homework. They also felt the lab manual needed refinement. Many of the students, however, indicated that there was nothing they disliked or would change about studio. The responses the students gave in the interviews corresponded closely with the exit surveys. The Likert scale questions on the exit surveys also indicated an overall positive reaction from the students. The students felt connections were being made among the lecture, the homework, and the laboratory activities. They were satisfied with the room arrangement and the usage of computers. They also felt that the integration of problem solving and laboratory work helped them learn physics.

5.2 *What perceptions do instructors teaching Engineering Physics have of the course in its new format?*

The overall reaction of the instructors was also positive. They felt that the new format was a better method of teaching as compared to the previous format and that the students were learning more in the new format. They liked the integration/connection between the homework and the laboratory activities, the group interaction and peer learning expected of the students, and the amount of student/teacher interaction. In addition, the faculty were having fun being in the laboratory and working with the students on experiments. Like the students, the negative aspects mentioned by the instructors tended to be focused on the operations of the studio and small details or irritants. They, too, felt rushed to finish in the time frame available and that the lab manual needed refinement. The most often cited negative aspect of studio from the instructor's perspective, however, was the time commitment. The faculty felt the strain in that their contact hours with the students had doubled from two hours a week to four hours a week. The teaching assistants, on the other hand, had approximately the same amount of contact hours, but their grading load increased dramatically.

5.3 *From what part of the course do students gain their physics knowledge?*

While none of the students were specifically asked this question, the interviewees did indicate, in how they answered certain other questions, where they perceived they gained their knowledge of physics. When asked what influenced them as they were taking the tests, the students indicated the lectures and homework as their primary source of reference and in nearly equal amounts. Studio and lab, combined were mentioned about half as often as the other two. The students could also indicate where they gained their knowledge when describing what they were thinking as they worked on a particular problem. If they referenced something they had done previously, they almost always mentioned a similar homework problem. On a few occasions, a particular lab activity was mentioned as being similar to the problem or question. This type of reaction is a reflection of how the students are tested on their knowledge of physics. Since the majority of their grade is based on their performance on the exams, and the majority of the exams is problem solving, the students are going to refer to the part of class where they learned their problem solving skills.

5.4 *What gains (or losses) have students made in their knowledge of physics?*

The gains that students have made in their knowledge of physics can be determined, conceptually, from their gains illustrated on the concept surveys. On the Force Concept Inventory, the students enrolled in the interactive-engagement courses made gains consistent with students at other institutions enrolled in interactive-engagement courses. They also made significant gains as compared to their counterparts who had previously been enrolled in the course in the traditional format. For the second semester course, the gains on the Engineering Physics II Conceptual Survey cannot be compared to students performances at other institutions or to our own students from the traditional format as the survey has only been administered to students enrolled in the interactive-engagement courses at Kansas State. However, the gains they made from pre-testing to post-testing on the survey were quite significant and comparable to the amount of gain students enrolled in interactive-engagement courses achieve on the Force Concept Inventory.

5.5 *Recommendations for Further Study*

As with all studies, further analysis could be made. In fact, a number of avenues could be explored with the existing data. First of all, almost nothing was done with the data collected from the tally of the scores of the exams given by the primary faculty member. The tally exists for all the parts of all exams which were given by the instructor for two and a half semesters. An analysis of theses scores could give insight to student understanding of the concepts as expressed/expected by the instructor's exam questions. Secondly, the descriptions of the students' thought process as they worked on specific problems were not analyzed in depth. The data from these interview questions could be used to try to understand, retroactively, these processes of the students as they worked on exam problems. Questions such as “what type of thinking process – expert, nïave, or mixed – do the students use as they approach exam problems” or “what misconceptions do students still hold after instruction” could be probed. Also, since after the first few sets of interviews, the students were all asked about the same problems, comparisons among students and their thinking processes could be made. Finally, a longitudinal study can be made with the conceptual surveys. A question that should be probed is whether the gains that were seen on the surveys were due to the change in course format to an interactive-engagement approach, or simply because a change was made.

5.6 *Summary*

At Kansas State we have altered the way in which we teach the introductory, calculus-based physics course from the traditional lecture/recitation/laboratory to an interactive, hands-on approach similar to those at some other large, research universities. One major difference of our method, as compared to the other methods, such as Studio Physics at Rensselaer Polytechnic Institute and SCALE-UP at North Carolina State University, is that we have retained the traditional lecture in our course. The second difference is that, while we do utilize computer technology in the classroom for the collection and analysis of data, computers are not emphasized as a learning tool. And yet, the change has been successful. The students view the change as being a positive improvement to their learning experience and have made significant gains in their conceptual understanding of physics. The instructors also view the changes to be positive. They are witnessing the students being more productive and involved in their learning of physics in a nurturing environment. With this in mind, it is conceivable that this New Studio method of teaching can be adapted and used at other institutions where it is not economically or practically feasible to completely eliminate the separate lecture from the course curriculum.

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Appendix A

The Force Concept Inventory (FCI) and cover sheet that were utilized during the Spring of 1999. Since all students enrolled in undergraduate physics laboratories were asked to participate, two questions were added. The questions asked if the students had taken physics and math in high school. Since this printed version was already in existence in the department, it was used with the Studio courses.

Force Concept Inventory

You have been selected to complete the Force Concept Inventory. Your participation in this questionnaire is voluntary though very importatn to academic research and the improvement of this course. Your participation in no way affects your grade in this course, and your instructors are not aware of your scores inthis inventory. Please complete the inventory as you receive it.

Please:

Do ***not write*** *anything on this questionnaire.*
Mark your answers on the Par SCORE computer card.
Make ***only one*** *mark per item.*
Do not *skip and questions and answer* ***ALL*** *questions.*
Avoid geissing. Your answers should reflect what **you** *personally think.*

On the ParSCORE computer card:

Use a **No. 2 pencil** *only, and follow marking instructions.*
Fill in your student ID number, course, and name.

Again, thank you for your participation.

1. Two metal balls are the same size but one weighs twice as much as the other. The balls are dropped from the roof of a single story building at the same instant of time. The time it takes the balls to reach the ground below will be:
   (A) about half as long for the heavier ball as for the lighter one.
   (B) about half as long for the lighter ball as for the heavier one.
   (C) about the same for both balls.
   (D) considerably less for the heavier ball, but not necessarily half as long.
   (E) considerably less for the lighter ball, but not necessarily half as long.

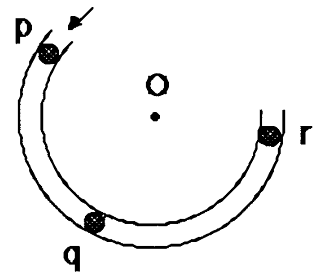
2. The two metal balls of the previous problem roll off a horizontal table with the same speed. In this situation:
   (A) both balls hit the floor at approximately the same horizontal distance from the base of the table.
   (B) the heavier ball hits the floor at about half the horizontal distance from the base of the table than does the lighter ball.
   (C) the lighter ball hits the floor at about half the horizontal distance from the base of the table than does the heavier ball.
   (D) the heavier ball hits the floor considerably closer to the base of the table than the lighter ball, but not necessarily at half the horizontal distance.
   (E) the lighter ball hits the floor considerably closer to the base of the table than the heavier ball, but not necessarily at half the horizontal distance.

3. A stone dropped from the roof of a single story building to the surface of the earth:
   (A) reaches a maximum speed quite soon after release and then falls at a constant speed thereafter.
   (B) speeds up as it falls because the gravitational attraction gets considerably stronger as the stone gets closer to the earth.
   (C) speeds up because of an almost constant force of gravity acting upon it.
   (D) falls because of the natural tendency of all objects to rest on the surface of the earth.
   (E) falls because of the combined effects of the force of gravity pushing it downward and the force of the air pushing it downward.

4. A large truck collides head-on with a small compact car. During the collision:
   (A) the truck exerts a greater amount of force on the car than the car exerts on the truck.
   (B) the car exerts a greater amount of force on the truck than the truck exerts on the car.
   (C) neither exerts a force on the other, the car gets smashed simply because it gets in the way of the truck.
   (D) the truck exerts a force on the car but the car does not exert a force on the truck.
   (E) the truck exerts the same amount of force on the car as the car exerts on the truck.

USE THE STATEMENT AND FIGURE BELOW TO ANSWER THE NEXT TWO QUESTIONS (5 and 6).

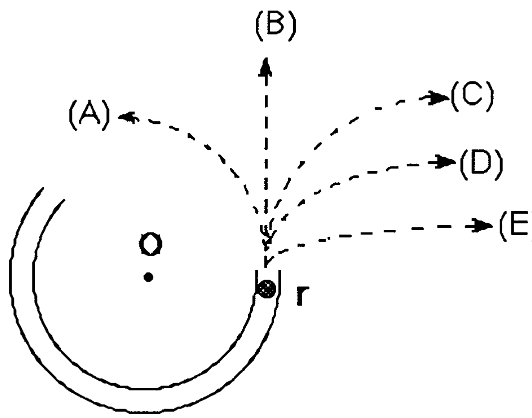
The accompanying figure shows a frictionless channel in the shape of a segment of a circle with center at "O". The channel has been anchored to a frictionless horizontal table top. You are looking down at the table. Forces exerted by the air are negligible. A ball is shot at high speed into the channel at "p" and exits at "r."



5. Consider the following distinct forces:
    1. A downward force of gravity.
    2. A force exerted by the channel pointing from q to O.
    3. A force in the direction of motion.
    4. A force pointing from O to q.

   Which of the above forces is (are) acting on the ball when it is within the frictionless channel at position "q"?

   (A) 1 only.
   (B) 1 and 2.
   (C) 1 and 3.
   (D) 1, 2, and 3.
   (E) 1, 3, and 4.

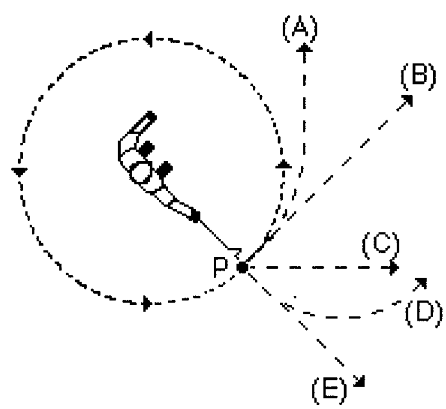


6. Which path in the figure at right would the ball most closely follow after it exits the channel at "r" and moves across the frictionless table top?

7. A steel ball is attached to a string and is swung in a circular path in a horizontal plane as illustrated in the accompanying figure.

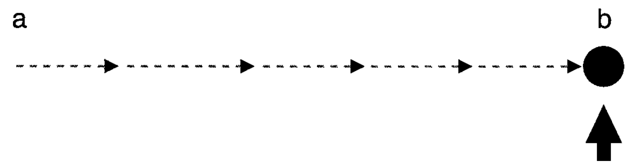
   At the point P indicated in the figure, the string suddenly breaks near the ball.

   If these events are observed from directly above as in the figure, which path would the ball most closely follow after the string breaks?

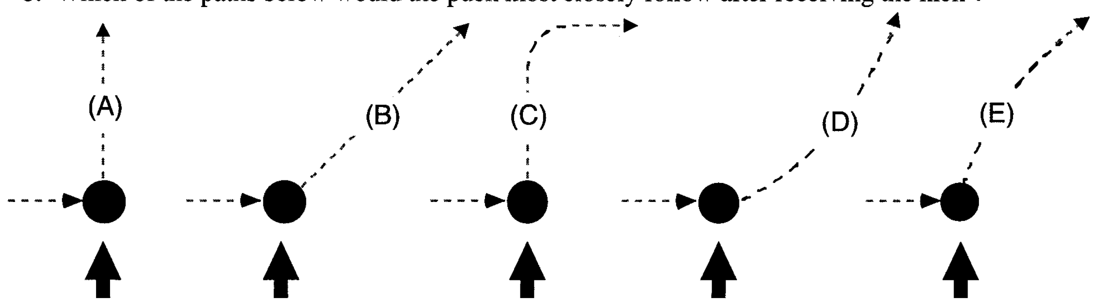


USE THE STATEMENT AND FIGURE BELOW TO ANSWER THE NEXT FOUR QUESTIONS (8 through 11).

The figure depicts a hockey puck sliding with constant speed v_o in a straight line from point "a" to point "b" on a frictionless horizontal surface. Forces exerted by the air are negligible. You are looking down on the puck. When the puck reaches point "b," it receives a swift horizontal kick in the direction of the heavy print arrow. Had the puck been at rest at point "b," then the kick would have set the puck in horizontal motion with a speed v_k in the direction of the kick.



8. Which of the paths below would the puck most closely follow after receiving the kick ?

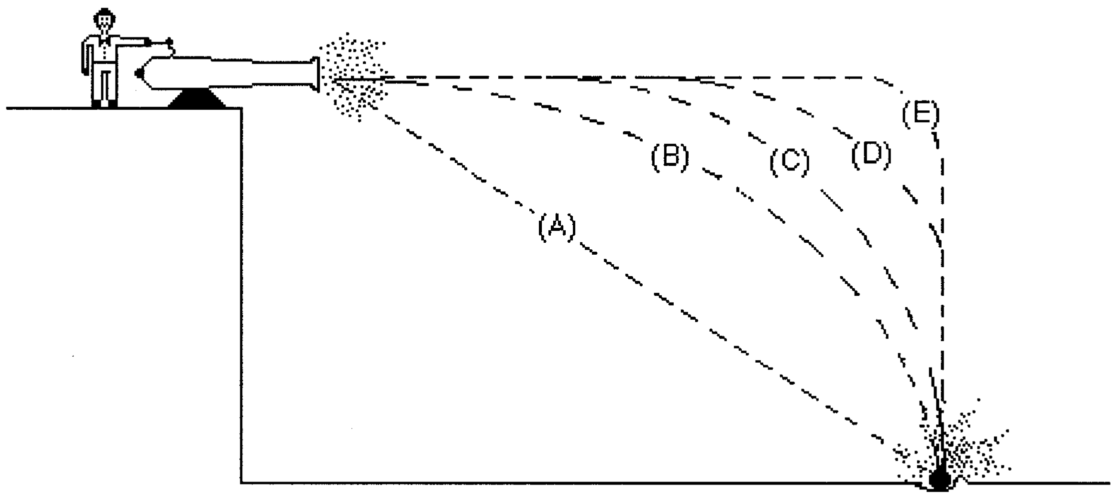


9. The speed of the puck just after it receives the kick is:
   (A) equal to the speed "v_o" it had before it received the kick.
   (B) equal to the speed "v_k" resulting from the kick and independent of the speed "v_o".
   (C) equal to the arithmetic sum of the speeds "v_o" and "v_k".
   (D) smaller than either of the speeds "v_o" or "v_k".
   (E) greater than either of the speeds "v_o" or "v_k", but less than the arithmetic sum of these two speeds.

10. Along the frictionless path you have chosen in question 8, the speed of the puck after receiving the kick:
   (A) is constant.
   (B) continuously increases.
   (C) continuously decreases.
   (D) increases for a while and decreases thereafter.
   (E) is constant for a while and decreases thereafter.

11. Along the frictionless path you have chosen in question 8, the main force(s) acting on the puck after receiving the kick is (are):
   (A) a downward force of gravity.
   (B) a downward force of gravity, and a horizontal force in the direction of motion.
   (C) a downward force of gravity, an upward force exerted by the surface, and a horizontal force in the direction of motion.
   (D) a downward force of gravity and an upward force exerted by the surface.
   (E) none. (No forces act on the puck.)

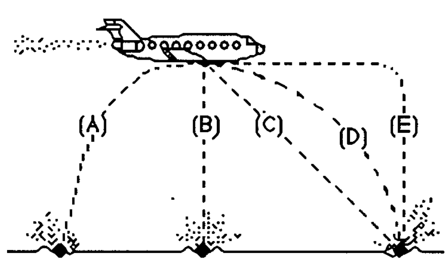
12. A ball is fired by a cannon from the top of a cliff as shown in the figure below. Which of the paths would the cannon ball most closely follow?



13. A boy throws a steel ball straight up. Consider the motion of the ball only after it has left the boy's hand but before it touches the ground, and assume that forces exerted by the air are negligible. For these conditions, the force(s) acting on the ball is (are):
    (A) a downward force of gravity along with a steadily decreasing upward force.
    (B) a steadily decreasing upward force from the moment it leaves the boy's hand until it reaches its highest point; on the way down there is a steadily increasing downward force of gravity as the object gets closer to the earth.
    (C) an almost constant downward force of gravity along with an upward force that steadily decreases until the ball reaches its highest point; on the way down there is only a constant downward force of gravity.
    (D) an almost constant downward force of gravity only.
    (E) none of the above. The ball falls back to ground because of its natural tendency to rest on the surface of the earth.

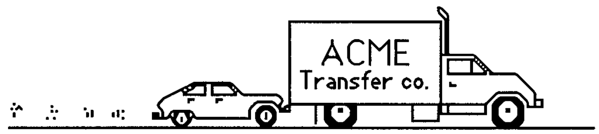
14. A bowling ball accidentally falls out of the cargo bay of an airliner as it flies along in a horizontal direction.

    As observed by a person standing on the ground and viewing the plane as in the figure at right, which path would the bowling ball most closely follow after leaving the airplane?



USE THE STATEMENT AND FIGURE BELOW TO ANSWER THE NEXT TWO QUESTIONS (15 and 16).

A large truck breaks down out on the road and receives a push back into town by a small compact car as shown in the figure below.



15. While the car, still pushing the truck, is speeding up to get up to cruising speed:
    (A) the amount of force with which the car pushes on the truck is equal to that with which the truck pushes back on the car.
    (B) the amount of force with which the car pushes on the truck is smaller than that with which the truck pushes back on the car.
    (C) the amount of force with which the car pushes on the truck is greater than that with which the truck pushes back on the car.
    (D) the car's engine is running so the car pushes against the truck, but the truck's engine is not running so the truck cannot push back against the car. The truck is pushed forward simply because it is in the way of the car.
    (E) neither the car nor the truck exert any force on the other. The truck is pushed forward simply because it is in the way of the car.

16. After the car reaches the constant cruising speed at which its driver wishes to push the truck:
    (A) the amount of force with which the car pushes on the truck is equal to that with which the truck pushes back on the car.
    (B) the amount of force with which the car pushes on the truck is smaller than that with which the truck pushes back on the car.
    (C) the amount of force with which the car pushes on the truck is greater than that with which the truck pushes back on the car.
    (D) the car's engine is running so the car pushes against the truck, but the truck's engine is not running so the truck cannot push back against the car. The truck is pushed forward simply because it is in the way of the car.
    (E) neither the car nor the truck exert any force on the other. The truck is pushed forward simply because it is in the way of the car.

17. An elevator is being lifted up an elevator shaft at a constant speed by a steel cable as shown in the figure below. All frictional effects are negligible. In this situation, forces on the elevator are such that:

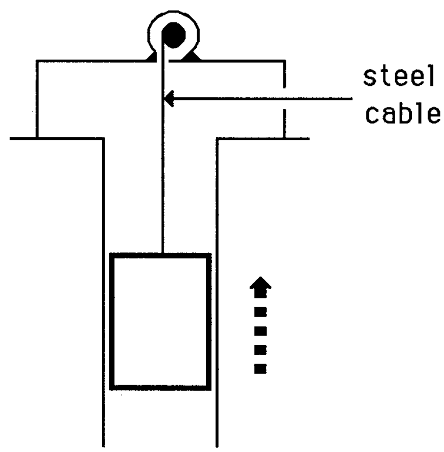
(A) the upward force by the cable is greater than the downward force of gravity.

(B) the upward force by the cable is equal to the downward force of gravity.

(C) the upward force by the cable is smaller than the downward force of gravity.

(D) the upward force by the cable is greater than the sum of the downward force of gravity and a downward force due to the air.

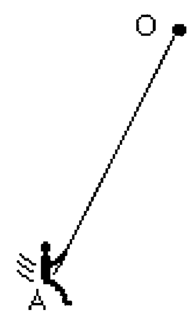
(E) none of the above. (The elevator goes up because the cable is being shortened, not because an upward force is exerted on the elevator by the cable).



Elevator going up
at constant speed

18. The figure below shows a boy swinging on a rope, starting at a point higher than A. Consider the following distinct forces:

1. A downward force of gravity.
2. A force exerted by the rope pointing from A to O.
3. A force in the direction of the boy's motion.
4. A force pointing from O to A.



Which of the above forces is (are) acting on the boy when he is at position A?

(A) 1 only.

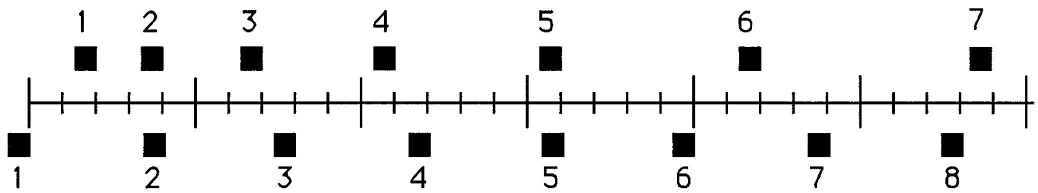
(B) 1 and 2.

(C) 1 and 3.

(D) 1, 2, and 3.

(E) 1, 3, and 4.

19. The positions of two blocks at successive 0.20-second time intervals are represented by the numbered squares in the figure below. The blocks are moving toward the right.



Do the blocks ever have the same speed?

(A) No.

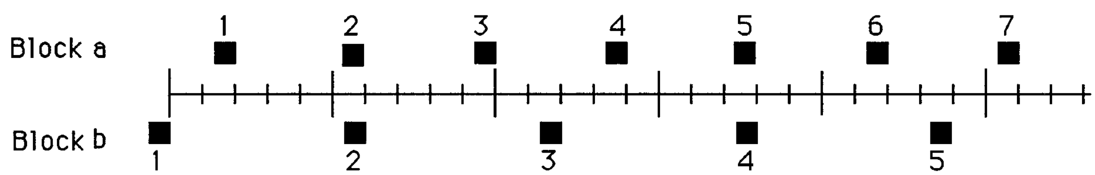
(B) Yes, at instant 2.

(C) Yes, at instant 5.

(D) Yes, at instants 2 and 5.

(E) Yes, at some time during the interval 3 to 4.

20. The positions of two blocks at successive 0.20-second time intervals are represented by the numbered squares in the figure below. The blocks are moving toward the right.



The accelerations of the blocks are related as follows:

(A) The acceleration of "a" is greater than the acceleration of " b".

(B) The acceleration of "a" equals the acceleration of "b". Both accelerations are greater than zero.

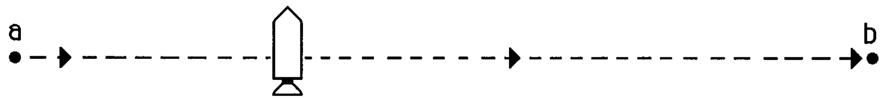
(C) The acceleration of "b" is greater than the acceleration of "a".

(D) The acceleration of "a" equals the acceleration of "b". Both accelerations are zero.

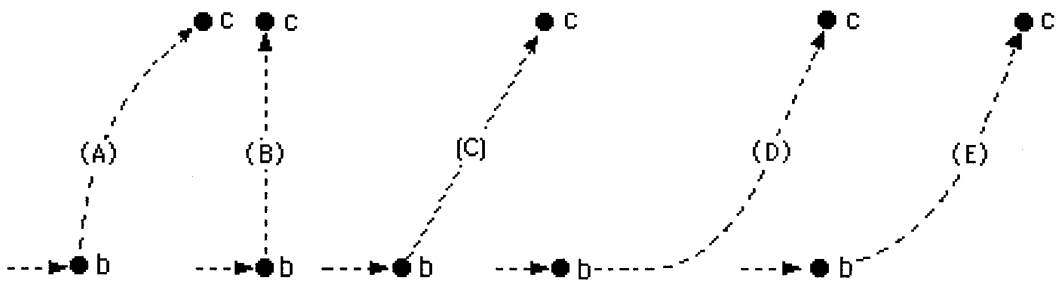
(E) Not enough information is given to answer the question.

USE THE STATEMENT AND FIGURE BELOW TO ANSWER THE NEXT FOUR QUESTIONS (21 through 24).

A rocket drifts sideways in outer space from point "a" to point "b" as shown below. The rocket is subject to no outside forces. Starting at position "b", the rocket's engine is turned on and produces a constant thrust (force on the rocket) at right angles to the line "ab". The constant thrust is maintained until the rocket reaches a point "c" in space.

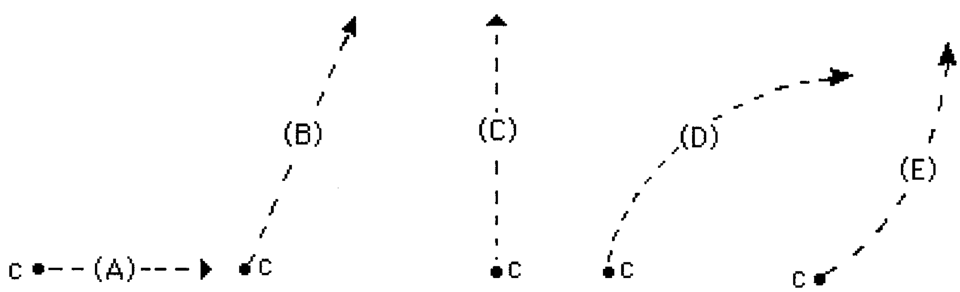


21. Which of the paths below best represents the path of the rocket between points "b" and "c"?



22. As the rocket moves from position"b" to position "c" its speed is:
   (A) constant.
   (B) continuously increasing.
   (C) continuously decreasing.
   (D) increasing for a while and constant thereafter.
   (E) constant for a while and decreasing thereafter.

23. At point "c" the rocket's engine is turned off and the thrust immediately drops to zero. Which of the paths below will the rocket follow beyond point "c"?



24. Beyond position "c" the speed of the rocket is:
   (A) constant.
   (B) continuously increasing.
   (C) continuously decreasing.
   (D) increasing for a while and constant thereafter.
   (E) constant for a while and decreasing thereafter.

25. A woman exerts a constant horizontal force on a large box. As a result, the box moves across a horizontal floor at a constant speed "v_o".

The constant horizontal force applied by the woman:

(A) has the same magnitude as the weight of the box.

(B) is greater than the weight of the box.

(C) has the same magnitude as the total force which resists the motion of the box.

(D) is greater than the total force which resists the motion of the box.

(E) is greater than either the weight of the box or the total force which resists its motion.

26. If the woman in the previous question doubles the constant horizontal force that she exerts on the box to push it on the same horizontal floor, the box then moves:

(A) with a constant speed that is double the speed "v_o" in the previous question.

(B) with a constant speed that is greater than the speed "v_o" in the previous question, but not necessarily twice as great.

(C) for a while with a speed that is constant and greater than the speed "v_o" in the previous question, then with a speed that increases thereafter.

(D) for a while with an increasing speed, then with a constant speed thereafter.

(E) with a continuously increasing speed.

27. If the woman in question 25 suddenly stops applying a horizontal force to the box, then the box will:

(A) immediately come to a stop.

(B) continue moving at a constant speed for a while and then slow to a stop.

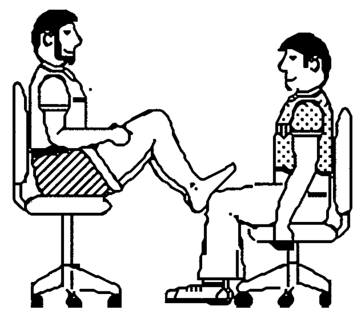
(C) immediately start slowing to a stop.

(D) continue at a constant speed.

(E) increase its speed for a while and then start slowing to a stop.

28. In the figure at right, student "a" has a mass of 95 kg and student "b" has a mass of 77 kg. They sit in identical office chairs facing each other.

Student "a" places his bare feet on the knees of student "b", as shown. Student "a" then suddenly pushes outward with his feet, causing both chairs to move.



During the push and while the students are still touching one another:

(A) neither student exerts a force on the other.

(B) student "a" exerts a force on student "b", but "b" does not exert any force on "a".

(C) each student exerts a force on the other, but "b" exerts the larger force.

(D) each student exerts a force on the other, but "a" exerts the larger force.

(E) each student exerts the same amount of force on the other.

29. An empty office chair is at rest on a floor. Consider the following forces:

1. A downward force of gravity.
2. An upward force exerted by the floor.
3. A net downward force exerted by the air.

Which of the forces is (are) acting on the office chair?

(A) 1 only.

(B) 1 and 2.

(C) 2 and 3.

(D) 1, 2, and 3.

(E) none of the forces. (Since the chair is at rest there are no forces acting upon it.)

30. Despite a very strong wind, a tennis player manages to hit a tennis ball with her racquet so that the ball passes over the net and lands in her opponent's court.

Consider the following forces:

1. A downward force of gravity.
2. A force by the "hit".
3. A force exerted by the air.

Which of the above forces is (are) acting on the tennis ball after it has left contact with the racquet and before it touches the ground?

(A) 1 only.

(B) 1 and 2.

(C) 1 and 3.

(D) 2 and 3.

(E) 1, 2, and 3.

31. Have you had a physics course in high school? (A) Yes (B) No

32. Have you had a math course in high school? (A) Yes (B) No

Appendix B

The Engineering Physics II Conceptual Survey with cover sheet.

Engineering Physics II Conceptual Survey

Your participation in this survey is completely voluntary though very important to academic research and the improvement of this course. Your participation in no way affects your grade in this course, and your instructors are not aware of your scores in this survey.

Instructions

Wait until you are told to begin, then turn to the next page and begin working. Answer each of the 38 question as accurately as you can. There is only one correct answer for each item. Feel free to use scratch paper if you wish.

Use a #2 pencil to record your answers on the Accu-Scan sheet. Please **do not** write in the survey booklet.

You will have approximately 30 minutes to complete the survey. If you finish early, check your work before handing in both the answer sheet and the survey booklet.

Thank you for your participation.

In any question referring to current, conventional current will be used (where conventional current is the flow of positive charges). In addition, all effects due to the earth's magnetic field will be so small that they will be ignored. Note that the term "particle" is meant to be an object without size or structure in this survey.

1. A hollow metal sphere is electrically neutral (no excess charge). A small amount of negative charge is suddenly placed at one point P on this metal sphere. If we check on this excess negative charge a few seconds later we will find one of the following possibilities:

   (A) All of the excess charge remains right around P.
   (B) The excess charge has distributed itself evenly over the outside surface of the sphere.
   (C) The excess charge is evenly distributed over the inside and outside surface.
   (D) Most of the charge is still at point P, but some will have spread over the sphere.
   (E) There will be no excess charge left.

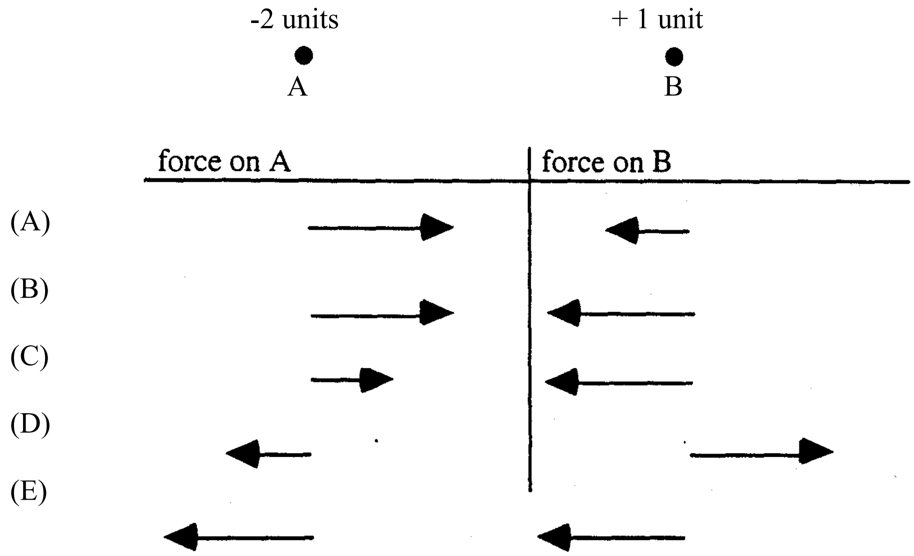
2. A hollow sphere made out of electrically insulating material is electrically neutral (no excess charge). A small amount of negative charge is suddenly placed at one point P on the outside of this sphere. If we check on this excess negative charge a few seconds later we will find one of the following possibilities

   (A) All of the excess charge remains right around P.
   (B) The excess charge has distributed itself evenly over the outside surface of the sphere.
   (C) The excess charge is evenly distributed over the inside and outside surface.
   (D) Most of the charge is still at point P, but some will have spread over the sphere.
   (E) There will be no excess charge left.

3. A positive charge is placed at rest at the center of a region of space in which there is a uniform, three-dimensional electric field. (A uniform field is one whose strength and direction are the same at all points within the region.) When the positive charge is released from rest in the uniform electric field, what will its subsequent motion be?

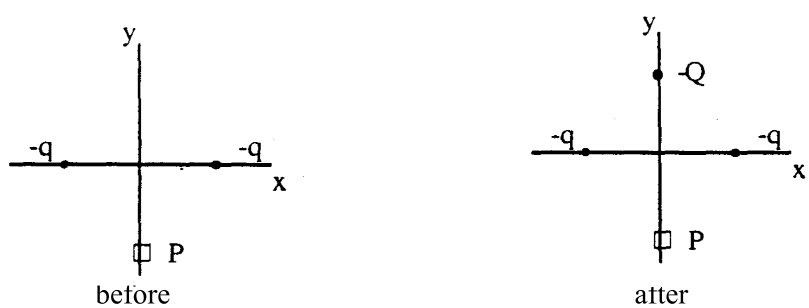
   (A) It will move at a constant speed.
   (B) It will move at a constant velocity.
   (C) It will move at a constant acceleration.
   (D) It will move with a linearly changing acceleration.
   (E) It will remain at rest in its initial position.

4. The picture below shows a particle (labeled B) which has a net electric charge of +1 unit. Several centimeters to the left is another particle (labeled A) which has a net charge of -2 units. Choose the pair of force vectors (the arrows) that correctly compare the electric force on A (caused by B) with the electric force on B (caused by A).



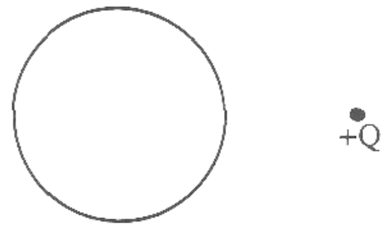
5. In the figure below, the electric field at point P is directed upward along the y-axis. If a negative charge -Q is added at a point on the positive y-axis, what happens to the field at P? (All of the charges are fixed in position.)

(A) Nothing since Q is on the y-axis.
(B) Strength will increase because Q is negative.
(C) Strength will decrease and direction may change because of the interactions between Q and the two negative q's.
(D) Strength will increase and direction may change because of the interactions between Q and the two negative q's.
(E) Cannot determine without knowing the forces Q exerts on the two negative q's.



6. The figure below shows a hollow uncharged metal sphere. Outside the sphere is a positive charge Q. What is the direction of the electric field at the center of the sphere.

(A) Left
(B) Right
(C) Up
(D) Down
(E) Zero field



7. What is the direction of the electric force on a negative charge at point P in the diagram below?

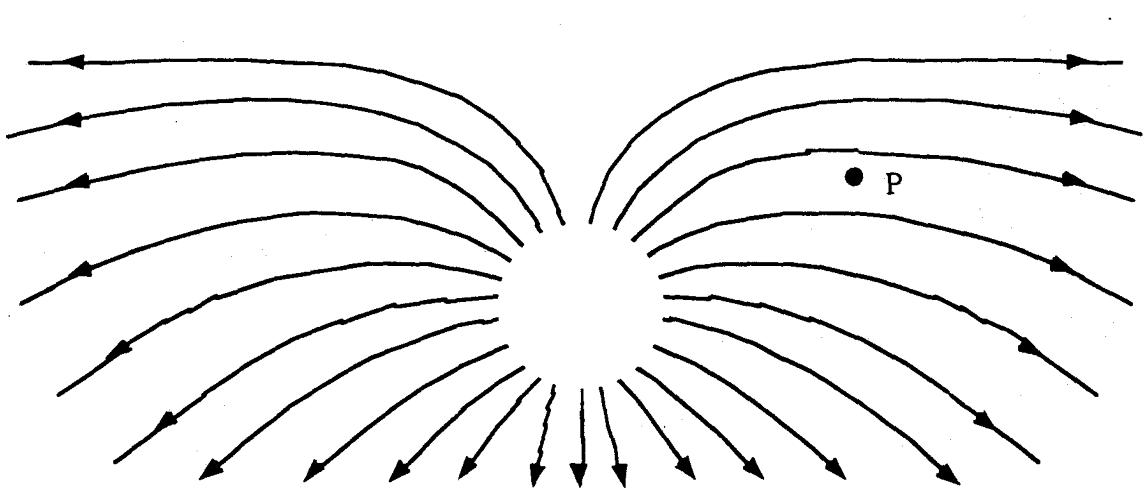
(A) ←

(B) ↙

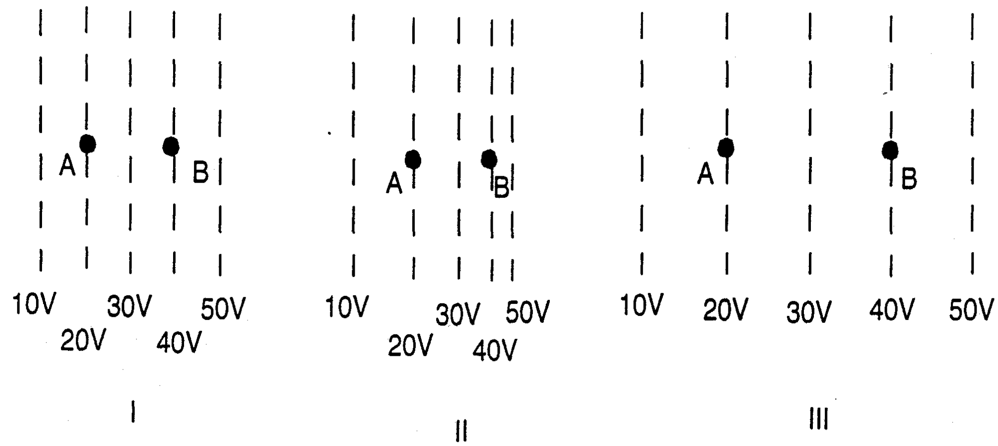
(C) →

(D) ↑

(E) the force is zero



FOR QUESTIONS 8-10 In the figures below, the dotted lines show the equipotential lines of electric fields. (A charge moving along a line of equal potential would have a constant electric potential energy.) A charged object is moved directly from point A to point B. The charge on the object is +1 μC.



8. How does the amount of work needed to move this charge compare for these three cases?

   (A) Most work required in I.
   (B) Most work required in II.
   (C) Most work required in III.
   (D) I and II require the same amount of work but less than III.
   (E) All three would require the same amount of work.

9. How does the magnitude of the electric field at B compare for these three cases?

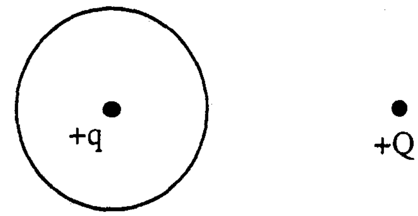
   (A) I > III > II
   (B) I > II > III
   (C) III > I > II
   (D) II > I > III
   (E) I = II = III

10. For case III what is the direction of the electric force exerted by the field on the + 1 μC charged object when at A and when at B?

   (A) left at A and left at B
   (B) right at A and right at B
   (C) left at A and right at B
   (D) right at A and left at B
   (E) no electric force at either.

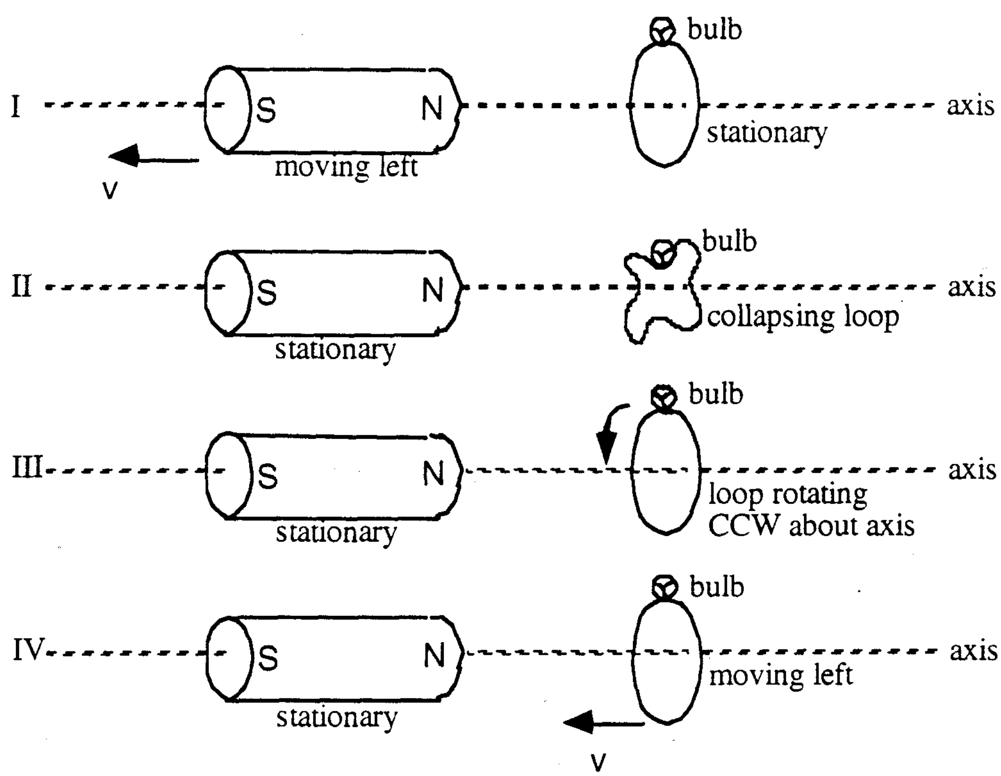
11. The figure below shows an electric charge q located at the center of a hollow uncharged metal sphere. Outside the sphere is a second charge Q. Both charges are positive. Choose the description below that describes the net electrical forces on each charge in this situation

(A) Both charges experience the same net force directed away from each other.
(B) No net force is experienced by either charge.
(C) There is no force on Q but a net force on q.
(D) There is no force on q but a net force on Q.
(E) Both charges experience a net force but they are different from each other.



12. These four separate figures involve a cylindrical magnet and a tiny light bulb connected to the ends of a loop of copper wire. The plane of the wire loop is perpendicular to the reference axis. The states of motion of the magnet and of the loop of wire are indicated in the diagram. Speed will be represented by v and CCW represents counter clockwise. In which of these figures will the light bulb be glowing?

(A) I, III, IV
(B) I, IV
(C) I, II, IV
(D) IV
(E) None of these



13. The diagram shows a wire with a large electric current i (⊙) coming out of the paper. In what direction would the magnetic field be at positions A and B?

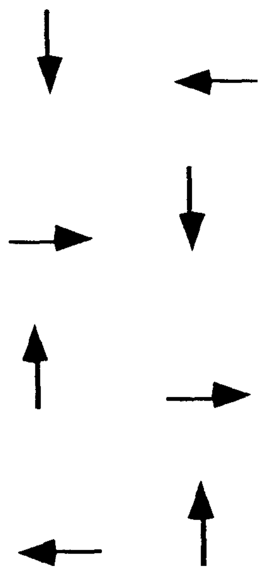
A B

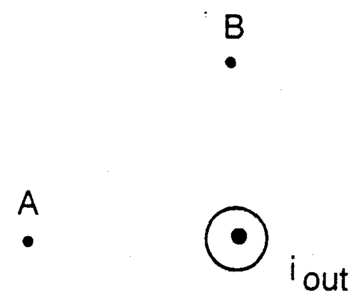
(A)

(B)

(C)

(D)

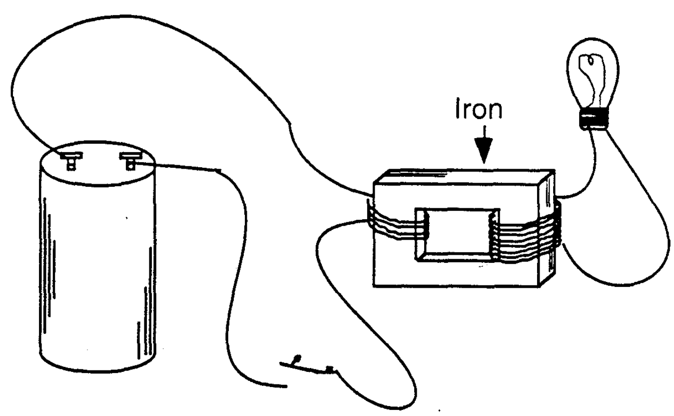




(E) None of these

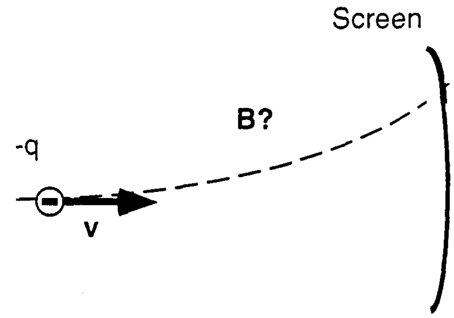
14. An insulated wire is wound around one side of a piece of iron and the ends of the wire are connected to the terminals of a battery. A second insulated wire is wound around the other side of the piece of iron and its ends connected across a light bulb. A switch, which can be opened or closed, is inserted in the wire to the battery. Which of the following statements about this arrangement is true?

(A) The bulb will light as long as the switch is closed.
(B) The bulb never lights because the two wires are not connected since they are insulated.
(C) The bulb lights momentarily only when the switch is first closed and not when it is opened.
(D) The bulb will light momentarily anytime the switch is closed or opened.
(E) The bulb never lights.



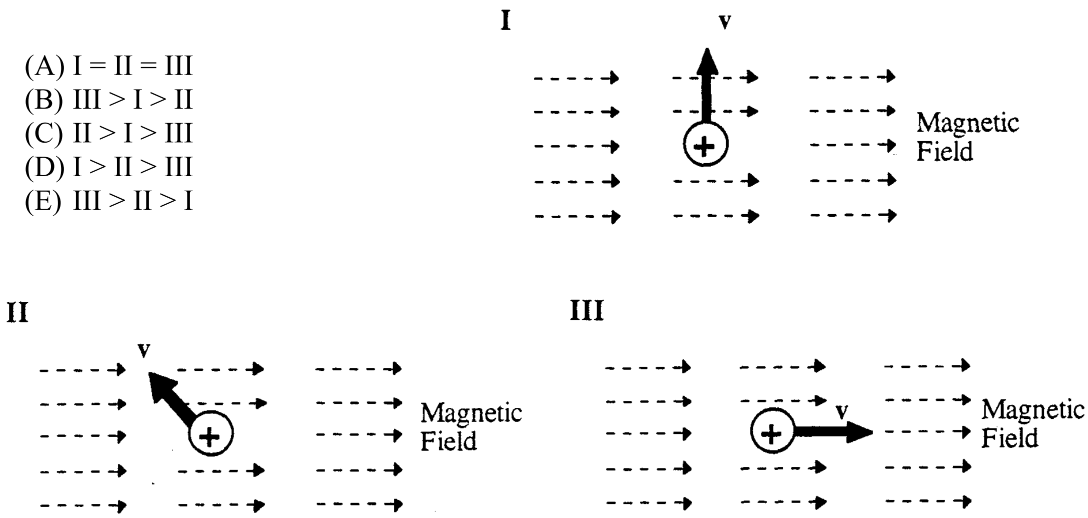
15. An electron moves horizontally toward a screen. The electron moves along the path that is shown because of a magnetic force caused by a magnetic field. In what direction does that magnetic field point?

(A) Toward the top of the page
(B) Toward the bottom of the page
(C) Into the page
(D) Out of the page
(E) The magnetic field is in the direction of the curved path.



16. The figures below represent positively charged particles moving in the same uniform magnetic field. The field is directed from left to right. All of the particles have the same charge and the same speed v. Rank these situations according to the magnitudes of the force exerted by the field on the moving charge, from greatest to least.

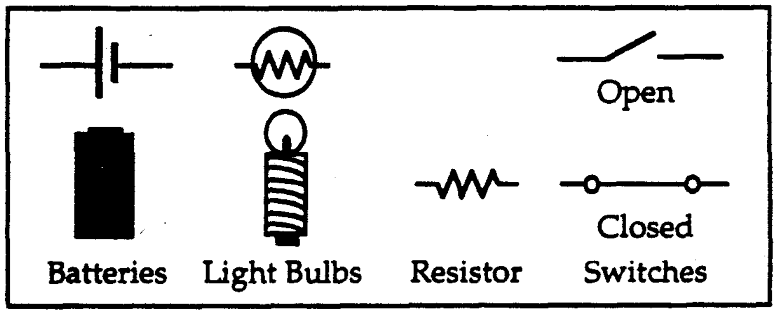
(A) I = II = III
(B) III > I > II
(C) II > I > III
(D) I > II > III
(E) III > II > I



17. Rank your confidence that your answers to questions 1-16 are correct.

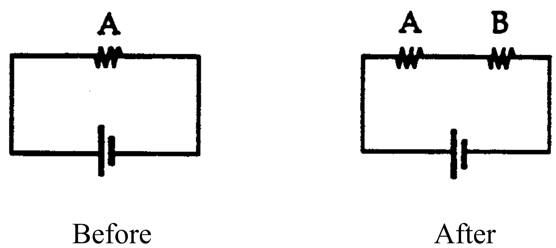
(A) I was just guessing
(B) I have a little confidence in my answers
(C) I am moderately confident
(D) I am rather confident that I got most of them right
(E) I am almost certain that they are correct.

For questions 18 – 26, all light bulbs, resistors, and batteries are identical unless you are told otherwise. The battery is ideal, that is to say, the internal resistance of the battery is negligible. In addition, the wires have negligible resistance. Below is a key to the symbols used on this survey. Study them carefully before you begin.



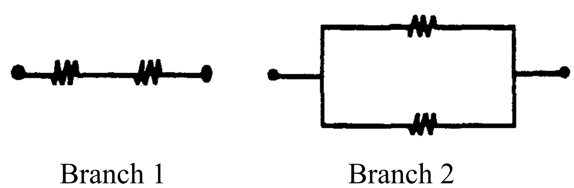
18. How does the power delivered to resistor A change when resistor B is added to the circuit? The power delivered to resistor A

(A) Quadruples (4 times)
(B) Doubles
(C) Stays the same
(D) Reduces by half
(E) Reduces by one quarter (1/4)



19. Compare the resistance of branch 1 with that of branch 2. A branch is a section of a circuit. The resistance of branch 1 is

(A) four times branch 2.
(B) double branch 2.
(C) the same as branch 2.
(D) half branch 2.
(E) one quarter (1/4) branch 2.

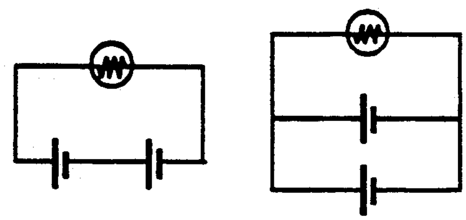


20. If you double the current through a battery, is the potential difference across a battery doubled?

(A) Yes, because Ohm's law says V = IR.
(B) Yes, because as you increase the resistance, you increase the potential difference.
(C) No, because as you double the current, you reduce the potential difference by half.
(D) No, because the potential difference is a property of the battery.
(E) No, because the potential difference is a property of everything in the circuit.

21. Compare the brightness of the bulb in circuit 1 with that in circuit 2. Which bulb is BRIGHTER?

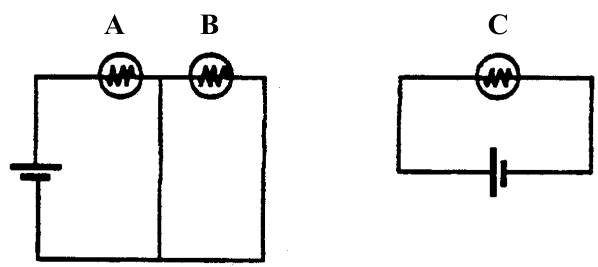
(A) Bulb in circuit 1 because two batteries in series provide less voltage.
(B) Bulb in circuit 1 because two batteries in series provide more voltage.
(C) Bulb in circuit 2 because two batteries in parallel provide less voltage.
(D) Bulb in circuit 2 because two batteries in
Circuit 2
parallel provide more voltage.
(E) Neither, they are the same.



Circuit 1

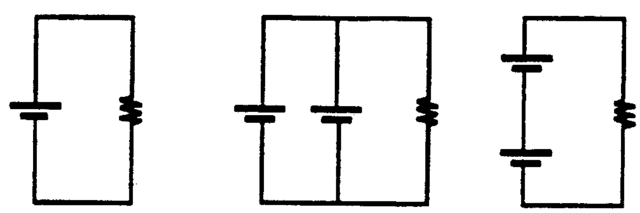
22. Compare the brightness of bulbs A, B, and C in these circuits. Which bulb or bulbs are the BRIGHTEST?

(A) A
(B) B
(C) C
(D) A = B
(E) A = C



23. Consider the power delivered to each of the resistors shown in the circuits below. Which circuit or circuits have the LEAST power delivered to them?

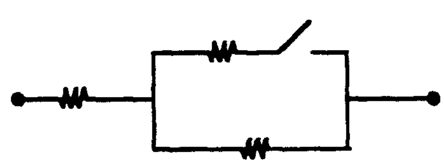
(A) Circuit 1
(B) Circuit 2
(C) Circuit 3
(D) Circuit 1 = Circuit 2
(E) Circuit 1 = Circuit 3



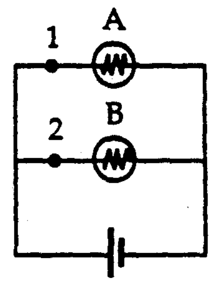
Circuit 1 Circuit 2 Circuit 3

24. How does the resistance between the endpoints change when the switch is closed?

(A) Increases by R
(B) Increases by R/2
(C) Stays the same
(D) Decreases by R/2
(E) Decreases by R

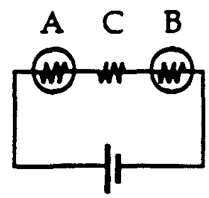


25. What happens to the brightness of bulbs A and B when a wire is connected between points 1 and 2?



(A) Both increase
(B) Both decrease
(C) They stay the same
(D) A becomes brighter than B
(E) Neither bulb will light

26. If you increase the resistance C, what happens to the brightness of bulbs A and B?



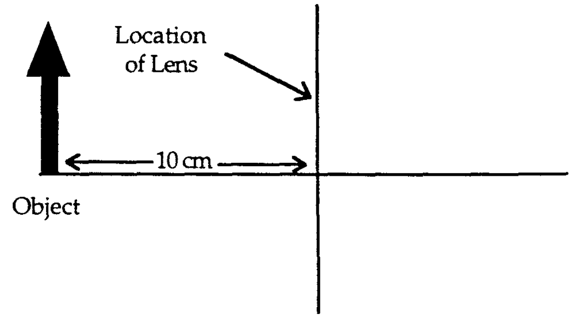
(A) A stays the same, B dims
(B) A dims, B stays the same
(C) A and B increase
(D) A and B decrease
(E) A and B remain the same

27. Rank your confidence that your answers to questions 18-26 are correct.

(A) I was just guessing
(B) I have a little confidence in my answers
(C) I am moderately confident
(D) I am rather confident that I got most of them right
(E) I am almost certain that they are correct.

Questions 28 - 30 refer to an object which is positioned 10 cm in front of a lens. The lens is either shaped like lens 1 or 2 shown below.
For each of the possible lenses, choose the one statement, A - E, which correctly describes the image formed by that lens. If none of the descriptions is correct, choose answer E.

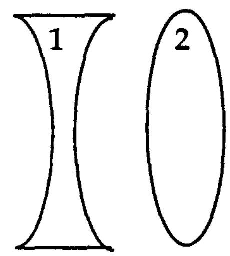
(A) The image is upright and larger than the object.
(B) The image is upright and smaller than the object.
(C) The image is inverted and larger than the object.
(D) The image is inverted and smaller than the object.
(E) None of the descriptions is correct.



28. The lens looks like 1 with focal length 4 cm.

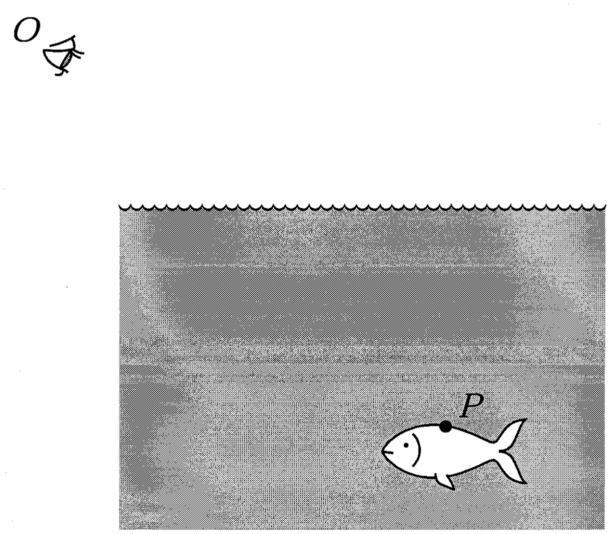
29. The lens looks like 2 with focal length 8 cm.

30. The lens looks like 2 with focal length 16 cm.



31. A fish swims below the surface of the water at P. An observer at 0 sees the fish at

(A) a greater depth than it really is.
(B) the same depth.
(C) a smaller depth than it really is.



32. For a given lens diameter, which light gives the best resolution in a microscope?

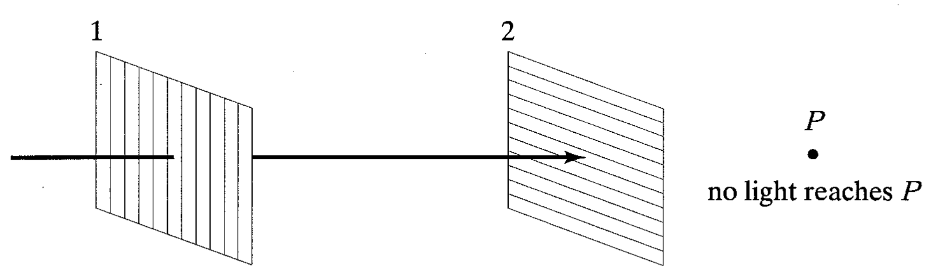
(A) red
(B) yellow
(C) green
(D) blue
(E) all give the same resolution

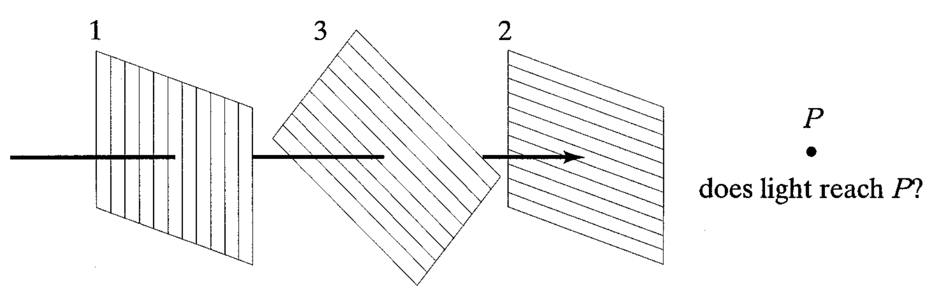
33. The light from a light source is unpolarized. The intensity at a certain distance is 100. When a piece of perfect Polaroid is placed in front of the source, the intensity passing through the Polaroid is

(A) 100
(B) 75
(C) 50
(D) 25
(E) 0

34. When a ray of light is incident on two polarizers with their polarization axes perpendicular, no light is transmitted. If a third polarizer is inserted between these two with its polarization axis at 45° to that of the other two, does any light get through to point P?

(A) yes
(B) no



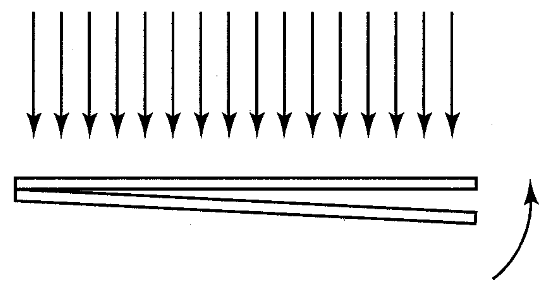


35. Diffraction occurs when light passes a

(A) pinhole.
(B) narrow slit.
(C) wide slit.
(D) sharp edge.
(E) all of the above.

36. Consider two identical microscope slides in air illuminated with monochromatic light. The bottom slide is rotated (counterclockwise about the point of contact in the side view) so that the wedge angle gets a bit smaller. What happens to the fringes?

(A) They are spaced farther apart.
(B) They are spaced closer together.
(C) They don't change.



37. Light from a laser passes through closely spaced slits and we see a pattern on a screen behind the slits. Suppose we block one slit of the two slits in this experiment. On a screen behind the slits, we see

(A) the same fringe pattern as with two slits.
(B) the same fringes as with two slits, but shifted over such that the maxima occurs where the minima used to be.
(C) nothing at all.
(D) a fairly uniformly illuminated elongated spot.
(E) none of the above.

38. Rank your confidence that your answers to questions 28-37 are correct.

(A) I was just guessing
(B) I have a little confidence in my answers
(C) I am moderately confident
(D) I am rather confident that I got most of them right
(E) I am almost certain that they are correct.

Appendix C

The Exit Survey given to students enrolled in EPI during the Spring of 2000 and the Spring of 2001. The Exit Surveys given to the students enrolled in EPI and EPII during the Fall of 2000 were identical, except for date and course name, to the survey given to the students the previous Spring. The EPII Exit Survey for Spring 2001 was identical, except for the course name, to the survey given to the EPI students.

Engineering Physics I Survey Spring 2000

The purpose of this survey is to learn your opinions about the reformation of Engineering Physics I into the Lecture/Studio format. Please answer the following questions.

Studio Time ________________

Major: ____________________

Circle one: Male or Female

1. What did you like about Studio?

2. What did you dislike about Studio?

3. What did you like about working in groups?

4. What did you dislike about working in groups?

5. For next semester, what would you definitely change about the way Studio is taught?

6. What would you definitely keep the same about the way Studio is taught?

7. Suppose you have a friend who is taking Engineering Physics I next semester. What advice would you give this friend?

Please indicate your level of agreement about each statement below by circling the appropriate response.

8. The connections between the homework and the laboratory work were always very clear and apparent.

   strongly disagree   disagree   neutral   agree   strongly agree

9. The connections between the laboratory work and the lecture were always very clear and apparent.

   strongly disagree   disagree   neutral   agree   strongly agree

10. The connections between the lecture and the homework were always very clear and apparent.

strongly disagree disagree neutral agree strongly agree

11. I am satisfied with the level of use of computers in Studio.

strongly disagree disagree neutral agree strongly agree

12. I am satisfied with the physical arrangement of the Studio room.

strongly disagree disagree neutral agree strongly agree

13. I am satisfied with the amount of interaction I had with the Studio instructors.

strongly disagree disagree neutral agree strongly agree

14. There is more to physics than problem solving.

strongly disagree disagree neutral agree strongly agree

15. The integration of problem solving and laboratory work helped me learn physics.

strongly disagree disagree neutral agree strongly agree

Please make any additional comments which could help us improve any aspect of Engineering Physics.

Engineering Physics I Survey Spring 2001

The purpose of this survey is to learn your opinions about Engineering Physics I in the Lecture/Studio format. Please answer the following questions.

Studio Time ________________ Major: _________________ Circle one: M or F

1. What did you like about Studio?

2. What did you dislike about Studio?

3. What did you like about working in groups?

4. What did you dislike about working in groups?

5. For next semester, what would you definitely change about the way Studio is taught?

6. What would you definitely keep the same about the way Studio is taught?

7. As you know, each Studio has three different instructors. We are interested in how each of these instructors was helpful as you were learning physics. Please comment below on the type and level of help that you received from each person

Class Assistant

Teaching Assistant

Faculty Member

8. Suppose you have a friend who is taking Engineering Physics I next semester. What advice would you give this friend?

Please indicate your level of agreement about each statement below by circling the appropriate response.

9. The connections between the homework and the laboratory work were always very clear and apparent.

strongly disagree   disagree   neutral   agree   strongly agree

10. The connections between the laboratory work and the lecture were always very clear and apparent.

strongly disagree   disagree   neutral   agree   strongly agree

11. The connections between the lecture and the homework were always very clear and apparent.

strongly disagree   disagree   neutral   agree   strongly agree

12. I am satisfied with the level of use of computers in Studio.

strongly disagree   disagree   neutral   agree   strongly agree

13. There is more to physics than problem solving.

strongly disagree   disagree   neutral   agree   strongly agree

14. The integration of problem solving and laboratory work helped me learn physics.

strongly disagree   disagree   neutral   agree   strongly agree

15. I am satisfied with the amount of interaction I had with the Studio instructors.

strongly disagree   disagree   neutral   agree   strongly agree

16. I felt most comfortable interacting about the homework problems with the

Class Assistant Teaching Assistant Faculty Member

17. I felt most comfortable interacting about the experiments with the

Class Assistant Teaching Assistant Faculty Member

18. Of the three studio instructors, the frequency with which my group (table) interacted with the **class assistant** was approximately

never seldom sometimes often always

19. Of the three studio instructors, the frequency with which my group (table) interacted with the **teaching assistant** was approximately

never seldom sometimes often always

20. Of the three studio instructors, the frequency with which my group (table) interacted with the **faculty member** was approximately

never seldom sometimes often always

Please make any additional comments which could help us improve any aspect of Engineering Physics.

Appendix D

Student Interview Protocols for Engineering Physics I Spring 2000. The first student protocol contained preliminary, demographic questions which were only asked at the first interview. The second protocol was used for the second interview while the third protocol was used for the third and fifth interviews. The fourth and fifth protocols were used for the fourth interview. The instructor gave a retake for the fourth exam which was optional. Some interviewees did not do the retake exam and were interviewed after the original. The remaining interviewees were interviewed after the retake.

Student Interview Protocols for Engineering Physics II Fall 2000. Each protocol varied slightly depending on the time during the semester. Thus all are included here.

Student Interview Protocols for Engineering Physics I Fall 2000. The second and fourth interviews followed the same protocol and thus only one is included. Three interviewees from the Engineering Physics I course in the Spring of 2000 retook the course in the Fall and were interviewed three times during the semester. The first and second interviews were identical.

Student Interview Protocols for Engineering Physics II Spring 2001. The first, third and fifth interview protocols were identical and, thus, only one is included here. Two interviewees from the Engineering Physics II course in the Fall of 2000 retook the course in the Spring. Neither completed the interview process, so only one protocol is included.

Interview Questions for EPI – Spring 2000:

Preliminary questions:

ID#

Year
Major
Race
Gender

Previous physics HS or other
Compare previous to current

Math background HS or other

1. What was your general feeling for this exam?

   - Did you understand the questions?

   - Did you think you were prepared? Why?

2. I noticed you did particularly well on this problem. What were you thinking?

   - Did anything help? What?

   - What can you think of from Studio which relates to this?

   - What else could we have done to help?

3. I noticed you didn't do well on this problem. What were you thinking?

   - Did anything help? What?

   - What can you think of from Studio which relates to this?

   - What else could we have done to help?

4. Think about class and the exam. What from the course influenced you while you were taking the exam?

   - What could we stress more to do better?

5. What about the course distracts you from learning what you would like?

6. Do you have any further comments you want to make?

Interview Questions for EPI – Spring 2000:

1. What was your general feeling for this exam?

   - Did you understand the questions?

   - Did you think you were prepared? Why?

2. I noticed you did particularly well on this problem. What were you thinking?

   - Did anything help? What?

   - What can you think of from Studio which relates to this?

   - What else could we have done to help?

3. I noticed you didn't do well on this problem. What were you thinking?

   - Did anything help? What?

   - What can you think of from Studio which relates to this?

   - What else could we have done to help?

4. Think about class and the exam. What from the course influenced you while you were taking the exam?

   - What could we stress more to do better?

5. What about the course distracts you from learning what you would like?

6. Do you have any further comments you want to make?

Interview Questions for EPI – Spring 2000:

1. What was your general feeling for this exam?

   - Did you understand the questions?

   - Did you think you were prepared? Why?

2. I noticed you did particularly well on this problem. What were you thinking?

   - What can you think of from Studio which relates to this?

   - What else could we have done to help?

3. I noticed you didn't do well on this problem. What were you thinking?

   - What can you think of from Studio which relates to this?

   - What else could we have done to help?

4. Think about the course and the exam. What from the course influenced you while you were taking the exam?

   - What could we do to do better job?

5. What about the course distracts you from learning what you would like?

6. Let's consider studio by itself for a moment.

   - How do you feel about it now compared to the beginning of the semester?

   - What do you like about it?
     How do you like working in groups?

   - What do you dislike about it?

   - What changes would you make?

7. Do you have any further comments you want to make?

Interview Questions for EPI – Spring 2000:

1. What was your general feeling for this exam?

   - How did you prepare?

2. I noticed you did particularly well on this problem. What were you thinking?

   - What can you think of from Studio which relates to this?

   - What else could we have done to help?

3. I noticed you didn't do well on this problem. What were you thinking?

   - What can you think of from Studio which relates to this?

   - What else could we have done to help?

4. Think about the course and the exam. What from the course influenced you while you were taking the exam?

   - What could we do to do better job?

5. What about the course distracts you from learning what you would like?

6. We used a computer simulation to study Kepler's Laws. Do you think it was effective? Why?

   - Should we do more things like it?
     Why? When?

7. Do you have any further comments you want to make?

Interview Questions for EPI – Spring 2000:

1. What was your general feeling for this exam?

   - Rate it from 1 – 5 with 5 being most positive.

   - The retake exam? Rate?

   - How did you prepare for the original exam?

   - What did you do differently for the retake exam?

2. I noticed you did particularly well on this problem. What were you thinking?

   - What can you think of from Studio which relates to this?

   - What else could we have done to help?

3. I noticed you didn't do well on this problem. What were you thinking?

   - What can you think of from Studio which relates to this?

   - What else could we have done to help?

4. Think about the course and the exam. What from the course influenced you while you were taking the exam?

   - What could we do to do better job?

5. What about the course distracts you from learning what you would like?

6. We used a computer simulation to study Kepler's Laws. Do you think it was effective? Why?

   - Should we do more things like it?
     Why? When?

7. Do you have any further comments you want to make?

Interview Questions for EPII – Fall 2000:

1. What was your general feeling for this exam?

   - On a scale of 1 – 5 with 5 being most positive, rate your confidence going into the exam.

   - Rate your confidence coming out of the exam.

   - Did you understand the questions?

   - How did you prepared for the exam?

2. I noticed you did particularly well on this problem. What were you thinking as you worked on it?

   - What can you think of from Studio which relates to this?

   - What else could we have done?

3. I noticed you didn't do well on this problem. What were you thinking as you worked on it?

   - What can you think of from Studio which relates to this?

   - What else could we have done?

4. Now consider this conceptual question. What were you thinking as you worked on it?

   - What can you think of from Studio which relates to this?

   - What else could we have done?

5. Think about course and the exam as a unit. What influenced you while you were taking the exam?

   - What could we stress more?

6. What about the course distracts you from learning what you would like?

7. Let's consider studio by itself for a moment.

   - How do you feel about it now compared to last semester?

   - What do you like about it?
     How do you like working in groups?

   - What do you dislike about it?

   - What changes would you make?

8. Do you have any further comments you want to make?

Interview Questions for EPII – Fall 2000:

1. What was your general feeling for this exam?

   - On a scale of 1 – 5 with 5 being most positive, rate your confidence going into the exam.

   - Rate your confidence coming out of the exam.

   - How did you prepared for the exam?

2. I noticed you did particularly well on this problem. What were you thinking as you worked on it?

   - What can you think of from Studio which relates to this?

   - What else could we have done?

3. I noticed you didn't do well on this problem. What were you thinking as you worked on it?

   - What can you think of from Studio which relates to this?

   - What else could we have done?

4. Now consider this conceptual question. What were you thinking as you worked on it?

   - What can you think of from Studio which relates to this?

   - What else could we have done?

5. Think about course and the exam as a unit. What influenced you while you were taking the exam?

   - What could we stress more?

6. What about the course distracts you from learning what you would like?

7. Let's consider studio by itself for a moment.

   - What do you like about it?

   - What do you dislike about it?

8. Do you have any further comments you want to make?

Interview Questions for EPII – Fall 2000:

1. What was your general feeling for this exam?

   - On a scale of 1 – 5 with 5 being most positive, rate your confidence going into the exam.

   - Rate your confidence coming out of the exam.

   - How did you prepared for the exam?

2. I noticed you did particularly well on this problem. What were you thinking as you worked on it?

   - What can you think of from Studio which relates to this?

   - What else could we have done?

3. I noticed you didn't do well on this problem. What were you thinking as you worked on it?

   - What can you think of from Studio which relates to this?

   - What else could we have done?

4. Now consider this conceptual question. What were you thinking as you worked on it?

   - What can you think of from Studio which relates to this?

   - What else could we have done?

5. Think about course and the exam as a unit. What influenced you while you were taking the exam?

   - What could we stress more?

6. What about the course distracts you from learning what you would like?

7. Let's consider studio by itself for a moment.

   - How do you feel about it now compared to the beginning of the semester?

   - What do you like about it?
     How do you like working in groups?

   - What do you dislike about it?

   - What changes would you make?

8. Do you have any further comments you want to make?

Interview Questions for EPII – Fall 2000:

1. What was your general feeling for this exam?

   - On a scale of 1 – 5 with 5 being most positive, rate your confidence going into the exam.

   - Rate your confidence coming out of the exam.

   - How did you prepared for the exam?

2. I noticed you did particularly well on this problem. What were you thinking as you worked on it?

   - What can you think of from Studio which relates to this?

   - What else could we have done?

3. I noticed you didn't do well on this problem. What were you thinking as you worked on it?

   - What can you think of from Studio which relates to this?

   - What else could we have done?

4. Now consider this conceptual question. What were you thinking as you worked on it?

   - What can you think of from Studio which relates to this?

   - What else could we have done?

5. Think about course and the exam as a unit. What influenced you while you were taking the exam?

   - What could we stress more?

6. What distracts you from learning what you would like?

7. Do you have any further comments you want to make?

Interview Questions for EPII – Fall 2000:

1. What was your general feeling for this exam?

   - On a scale of 1 – 5 with 5 being most positive, rate your confidence going into the exam.

   - Rate your confidence coming out of the exam.

   - How did you prepared for the exam?

2. I noticed you did particularly well on this problem. What were you thinking as you worked on it?

   - What can you think of from Studio which relates to this?

   - What else could we have done?

3. I noticed you didn't do well on this problem. What were you thinking as you worked on it?

   - What can you think of from Studio which relates to this?

   - What else could we have done?

4. Now consider this conceptual question. What were you thinking as you worked on it?

   - What can you think of from Studio which relates to this?

   - What else could we have done?

5. Think about course and the exam as a unit. What influenced you while you were taking the exam?

   - What could we stress more?

6. What about the course distracts you from learning what you would like?

7. Now that we are at the end of the semester, let's consider studio by itself for a moment.

   - How do you feel about it now compared to the beginning of the semester?

   - What do you like about it?
     How do you like working in groups?

   - What do you dislike about it?

   - What changes would you make?

8. Do you have any further comments you want to make?

Interview Questions for EPI – Fall 2000:

Preliminary questions:

ID#

Year

Major

Race

Gender

Previous physics   HS or other

Compare previous to current

Math background   HS or other

1. What was your general feeling for this exam?

   - On a scale of 1 – 5 with 5 being most positive, rate your confidence going into the exam.

   - Rate your confidence coming out of the exam.

   - Did you understand the questions?

   - How did you prepared for the exam?

2. I noticed you did particularly well on this problem. What were you thinking as you worked on it?

   - What can you think of from Studio which relates to this?

   - What else could we have done?

3. I noticed you didn't do well on this problem. What were you thinking as you worked on it?

   - What can you think of from Studio which relates to this?

   - What else could we have done?

4. Think about course and the exam as a unit. What influenced you while you were taking the exam?

   - What could we stress more?

5. What about the course distracts you from learning what you would like?

6. Do you have any further comments you want to make?

Interview Questions for EPI – Fall 2000:

1. What was your general feeling for this exam?

   - On a scale of 1 – 5 with 5 being most positive, rate your confidence going into the exam.

   - Rate your confidence coming out of the exam.

   - Did you understand the questions?

   - How did you prepared for the exam?

2. I noticed you did particularly well on this problem. What were you thinking as you worked on it?

   - What can you think of from Studio which relates to this?

   - What else could we have done?

3. I noticed you didn't do well on this problem. What were you thinking as you worked on it?

   - What can you think of from Studio which relates to this?

   - What else could we have done?

4. Think about course and the exam as a unit. What influenced you while you were taking the exam?

   - What could we stress more?

5. What about the course distracts you from learning what you would like?

6. Do you have any further comments you want to make?

Interview Questions for EPI – Fall 2000:

1. What was your general feeling for this exam?

   - On a scale of 1 – 5 with 5 being most positive, rate your confidence going into the exam.

   - Rate your confidence coming out of the exam.

   - Did you understand the questions?

   - How did you prepared for the exam?

2. I noticed you did particularly well on this problem. What were you thinking as you worked on it?

   - What can you think of from Studio which relates to this?

   - What else could we have done?

3. I noticed you didn't do well on this problem. What were you thinking as you worked on it?

   - What can you think of from Studio which relates to this?

   - What else could we have done?

4. Think about course and the exam as a unit. What influenced you while you were taking the exam?

   - What could we stress more?

5. What about the course distracts you from learning what you would like?

6. Let's consider studio by itself for a moment.

   - How do you feel about it now compared to the beginning of the semester?

   - What do you like about it?
     How do you like working in groups?

   - What do you dislike about it?

   - What changes would you make?

7. Do you have any further comments you want to make?

Interview Questions for EPI – Fall 2000:

1. What was your general feeling for this exam?

   - On a scale of 1 – 5 with 5 being most positive, rate your confidence going into the exam.

   - Rate your confidence coming out of the exam.

   - Did you understand the questions?

   - How did you prepared for the exam?

2. I noticed you did particularly well on this problem. What were you thinking as you worked on it?

   - What can you think of from Studio which relates to this?

   - What else could we have done?

3. I noticed you didn't do well on this problem. What were you thinking as you worked on it?

   - What can you think of from Studio which relates to this?

   - What else could we have done?

4. Think about course and the exam as a unit. What influenced you while you were taking the exam?

   - What could we stress more?

5. What about the course distracts you from learning what you would like?

6. Now that we are at the end of the semester, let's consider studio by itself for a moment.

   - How do you feel about it now compared to the beginning of the semester?

   - What do you like about it?
     How do you like working in groups?

   - What do you dislike about it?

   - What changes would you make?

7. Do you have any further comments you want to make?

Interview Questions for Retakers of EPI – Fall 2000:

1. What was your general feeling for this exam?

   - On a scale of 1 – 5 with 5 being most positive, rate your confidence going into the exam.

   - Rate your confidence coming out of the exam.

   - How did you prepared for the exam?

2. What are you doing differently this time compared to last semester?

3. Is taking studio a second time helping you master the concepts?

   - Why?

4. What changes have occurred in studio which are good?

   - Bad?

5. Do you have any further comments you want to make?

Interview Questions for Retakers of EPI – Fall 2000:

1. What was your general feeling for this exam?

   - On a scale of 1 – 5 with 5 being most positive, rate your confidence going into the exam.

   - Rate your confidence coming out of the exam.

   - How did you prepared for the exam?

2. What are you doing differently this time compared to last semester?

3. Is taking studio a second time effecting your understanding of the concepts?

   - Why?

4. What changes have occurred in studio which are good?

   - Bad?

5. Now that we are at the end of the semester, let's consider studio by itself for a moment.

   - How do you feel about it now compared to the beginning of the semester?

   - What do you like about it?
     How do you like working in groups?

   - What do you dislike about it?

   - What changes would you make?

6. Do you have any further comments you want to make?

Interview Questions for EPII – Spring 2001:

1. What was your general feeling for this exam?

   - On a scale of 1 – 5 with 5 being most positive, rate your confidence going into the exam.

   - Rate your confidence coming out of the exam.

   - Did you understand the questions?

   - How did you prepared for the exam?

2. I noticed you did particularly well on this problem. What were you thinking as you worked on it?

   - What can you think of from Studio which relates to this?

   - What else could we have done?

3. I noticed you didn't do well on this problem. What were you thinking as you worked on it?

   - What can you think of from Studio which relates to this?

   - What else could we have done?

4. Now consider this conceptual question. What were you thinking as you worked on it?

   - What can you think of from Studio which relates to this?

   - What else could we have done?

5. Think about course and the exam as a unit. What influenced you while you were taking the exam?

   - What could we stress more?

6. What distracts you from learning what you would like?

7. Let's consider studio by itself for a moment.

   - How do you feel about it now compared to last semester?

   - What do you like about it?
     How do you like working in groups?

   - What do you dislike about it?

   - What changes would you make?

8. Do you have any further comments you want to make?

Interview Questions for EPII – Spring 2001:

1. What was your general feeling for this exam?

   - On a scale of 1 – 5 with 5 being most positive, rate your confidence going into the exam.

   - Rate your confidence coming out of the exam.

   - How did you prepared for the exam?

2. I noticed you did particularly well on this problem. What were you thinking as you worked on it?

   - What can you think of from Studio which relates to this?

   - What else could we have done?

3. I noticed you didn't do well on this problem. What were you thinking as you worked on it?

   - What can you think of from Studio which relates to this?

   - What else could we have done?

4. Now consider this conceptual question. What were you thinking as you worked on it?

   - What can you think of from Studio which relates to this?

   - What else could we have done?

5. Think about course and the exam as a unit. What influenced you while you were taking the exam?

   - What could we stress more?

6. What about the course distracts you from learning what you would like?

7. What do you think about having an exam after only two weeks?

8. Do you have any further comments you want to make?

Interview Questions for EPII – Spring 2001:

1. What was your general feeling for this exam?

   - On a scale of 1 – 5 with 5 being most positive, rate your confidence going into the exam.

   - Rate your confidence coming out of the exam.

   - How did you prepared for the exam?

2. I noticed you did particularly well on this problem. What were you thinking as you worked on it?

   - What can you think of from Studio which relates to this?

   - What else could we have done?

3. I noticed you didn't do well on this problem. What were you thinking as you worked on it?

   - What can you think of from Studio which relates to this?

   - What else could we have done?

4. Now consider this conceptual question. What were you thinking as you worked on it?

   - What can you think of from Studio which relates to this?

   - What else could we have done?

5. Think about course and the exam as a unit. What influenced you while you were taking the exam?

   - What could we stress more?

6. What about the course distracts you from learning what you would like?

7. Do you have any further comments you want to make?

Interview Questions for Retakers – EPII Spring 2001:

1. What was your general feeling for this exam?

   - On a scale of 1 – 5 with 5 being most positive, rate your confidence going into the exam.

   - Rate your confidence coming out of the exam.

   - How did you prepared for the exam?

   - What are you doing differently semester time compared to last semester?

2. I noticed you did particularly well on this problem. What were you thinking as you worked on it?

   - What can you think of from Studio which relates to this?

   - What else could we have done?

3. I noticed you didn't do well on this problem. What were you thinking as you worked on it?

   - What can you think of from Studio which relates to this?

   - What else could we have done?

4. Now consider this conceptual question. What were you thinking as you worked on it?

   - What can you think of from Studio which relates to this?

   - What else could we have done?

5. Think about course and the exam as a unit. What influenced you while you were taking the exam?

   - What could we stress more?

6. What about the course distracts you from learning what you would like?

7. Is taking studio a second time effecting your understanding of the concepts?
   Why?

8. Let's consider studio by itself for a moment.

   - How do you feel about it now compared to the beginning of the semester?

   - What do you like about it?
     How do you like working in groups?

   - What do you dislike about it?

- What changes have occurred in EPII studio which are good? Bad?

- What changes would you make?

9. Do you have any further comments you want to make?

Appendix E

Instructor Interview Protocols for Spring 2000. The first interview with the instructors was very unstructured, however, three basic questions were asked. The second interview probed a few issues which had been raised in the weekly meeting. The third interview was asking about overall opinion of the course.

Instructor Interview Protocols for Fall 2000 and Spring 2001. The interview questions for both semesters were more structured. They did not change from one semester to the next.

Interview Questions:

1. How's it going?
2. Do you think the students are learning more? Why?
3. What can we do to improve it?
4. Do you have any further comments you want to make?

Interview Questions:

1. How's it going?
2. What is your opinion of the number of instructors in the classroom?
3. How is the integration working?
4. What do you think about having the students do a few formal lab reports?
5. How do you see Studio surviving in the Department?
6. Do you have any further comments you want to make?

Interview Questions:

1. What is your overall feeling of how the course went?
2. What do you think are its chances of survival?
3. Do you think it was a success?
4. Do you have any further comments you want to make?

Faculty/Instructor Interview Protocol 1

1. How's it going?

2. What are/were your expectations for the course?

   Are we meeting them?

3. What are some positive aspects of Studio?

4. What are some negative aspects of Studio?

5. Do you have any further comments you wish to make?

Faculty/Instructor Interview Protocol 2

1. How’s it going?

2. Have your expectations for the course been fulfilled?

3. Have your fears been fulfilled?

4. What is your reaction when something doesn’t go as you expected?

   What do you do to make it a positive experience?

5. What are some positive aspects of Studio?

6. What are some negative aspects of Studio?

7. Do you have any further comments you wish to make?

Faculty/Instructor Interview Protocol 3

1. How did it go?

2. In your first interview you said your expectations were . . .

   - Were these expectations met? Why or why not?

   - What would need to change to have your expectations met?

3. How did you manage your time (in and out of class) for teaching studio?

   - How does that compare to teaching recitation/laboratory in the past?

   - Was the way you managed your time satisfactory?

4. What are some positive aspects of Studio compared to the previous format?

   - What are some negative aspects?

5. If you had the opportunity, what changes would you make to Studio?

6. What recommendations would you make to someone teaching a Studio next semester?

7. If you are teaching studio next semester, what would you do differently?
   - the same?

8. Do you have any further comments you wish to make?