DEVELOPMENT AND EVALUATION OF CLICKER METHODOLOGY FOR INTRODUCTORY PHYSICS COURSES

DISSERTATION

Presented in Partial Fulfillment of the Requirements for
the Degree Doctor of Philosophy in the Graduate
School of The Ohio State University

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*****

The Ohio State University
2009

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ABSTRACT

Many educators understand that lectures are cost effective but not learning efficient, so continue to search for ways to increase active student participation in this traditionally passive learning environment. In-class polling systems, or “clickers”, are inexpensive and reliable tools allowing students to actively participate in lectures by answering multiple-choice questions. Students assess their learning in real time by observing instant polling summaries displayed in front of them. This in turn motivates additional discussions which increase the opportunity for active learning.

We wanted to develop a comprehensive clicker methodology that creates an active lecture environment for a broad spectrum of students taking introductory physics courses. We wanted our methodology to incorporate many findings of contemporary learning science. It is recognized that learning requires active construction; students need to be actively involved in their own learning process. Learning also depends on preexisting knowledge; students construct new knowledge and understandings based on what they already know and believe. Learning is context dependent; students who have learned to apply a concept in one context may not be able to recognize and apply the same concept in a different context, even when both contexts are considered to be isomorphic by experts. On this basis, we developed question sequences, each involving
the same concept but having different contexts. Answer choices are designed to address students preexisting knowledge. These sequences are used with the clickers to promote active discussions and multiple assessments.

We have created, validated, and evaluated sequences sufficient in number to populate all of introductory physics courses. Our research has found that using clickers with our question sequences significantly improved student conceptual understanding. Our research has also found how to best measure student conceptual gain using research-based instruments. Finally, we discovered that students need to have full access to the question sequences after lectures to reap the maximum benefit.

Chapter 1 provides an introduction to our research. Chapter 2 provides a literature review relevant for our research. Chapter 3 discusses the creation of the clicker question sequences. Chapter 4 provides a picture of the validation process involving both physics experts and the introductory physics students. Chapter 5 describes how the sequences have been used with clickers in lectures. Chapter 6 provides the evaluation of the effectiveness of the clicker methodology. Chapter 7 contains a brief summary of research results and conclusions.
Dedicated to my father
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I thank God for making it possible to meet all these people, without whom I
would not be where I am today.
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PUBLICATIONS

Research Publication


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A recent report by the National Academies indicates that, in the United States, about 30% of the students entering college intend to major in science or engineering, and this percentage has remained fairly constant over the past 20 years [Augustine, 2007]. These students generally take introductory physics courses as part of their science or engineering major requirements. As highlighted in a recent report that summarized key findings from research on learners and learning and on teachers and teaching, students must have a functioning knowledge structure made up of deep foundation of facts, understanding of facts and concepts in the context of a conceptual framework, and organization that facilitate retrieval and application in order to develop competence in the subject [Bransford, 2000]. To learn and gain competence with scientific concepts, each concept must also be accompanied by ancillary knowledge specifying when and how it is to be used [Reif, 1992].

However, most students taking introductory physics do not develop this level of competence. As McDermott points out, these students often do not “apply appropriate concepts and physical principles in situations not previously encountered” [McDermott, 1993]. Competence with concepts allows experts to tackle new situations [Bransford,
But most of the students taking traditional forms of these courses continue to have difficulties obtaining competence [Arons, 1981; Peters, 1982]. And students know it themselves. About 40% of students also mention conceptual difficulties as a concern, and about 36% of students who switch to non-STEM (science, technology, engineering, and mathematics) majors mention conceptual difficulties as a reason [Seymour, 1992]. This is not surprising, since conceptual understanding cannot simply be transferred from teachers to students – it must be constructed by the students [von Glasersfeld, 1995]. However, most physics faculty who teach these courses are more in line with the traditional transmissionist view of student learning [Redish, 2000].

Traditional introductory physics courses utilize lecture, recitation, and laboratory sessions to teach physics. The size of the lecture frequently is determined by the seating capacity of the lecture hall and the availability of enrolled students [Bloom, 1953]. For example, at the Ohio State University (OSU), each physics course typically has approximately 200 students. The size of each recitation and laboratory sessions is also limited by the occupant capacity of the room but typically is smaller to allow discussion and interaction with the instructor. At OSU, a maximum of 28 students can enroll for each recitation and laboratory session. Some students thrive in this traditional environment, but most students do not develop functional understanding of physics [McDermott, 2001].

Our clicker research focused on developing a methodology that encourages active student participation in traditionally passive lectures and increases their conceptual understanding. During the process, we discovered many aspects that can affect the proper measurement of gain in students’ conceptual learning and the measurable
effectiveness of our clicker methodology. With all these aspects controlled, our clicker methodology produced positive impacts for students.

Our clicker research can be divided into four major parts: creating question sequences, validating them, using them repeatedly in lectures, and evaluating resulting learning gains. Question sequence creation is discussed in Chapter 3. Validation of these sequences is discussed in Chapter 4. Implementation is discussed in Chapter 5. The resulting learning gains are discussed in Chapter 6.

Clicker question sequences were designed to include various research findings that are described in more detail in the literature review chapter of this dissertation. Previous research is used in the creation process. For example, students’ preconcepts were integrated into the questions as attractive distracters and each question in a sequence featured a different context but same concept to help students construct their own learning.

We worked with physics experts and beginning students to validate questions. During the process, we conducted one-on-one interviews with students to make sure the clicker sequences are valid for students taking introductory physics courses. We discovered that beginning students pick up many validity issues missed by experts [Ding, 2009]. We also have tested some sequences that had these issues resolved in-class to obtain large statistics in-class data, and the data indicate improvements. From these we have concluded that both the expert validation and student validation are needed to make sure these question sequences are interpreted correctly by the introductory physics students.
The method of implementation used is similar to Peer Instruction [Mazur, 1997] and provides the kind of active learning environment that promotes learning. The main difference is that our methodology makes uses of sequences of questions on a concept rather than one single question. We believe this enables students to learn the concept in multiple contexts, get multiple formative assessments in real time, and allow multiple discussions about the concept.

Therefore, our clicker methodology is based on using research-based sequences of multiple-choice questions which focus on the same concept presented in a variety of contexts. During lectures, questions are shown in sequence on a large viewing screen, and students use their clickers to select multiple-choice answers. Voting summaries are immediately displayed to the class. These frequent formative assessments make students’ thinking visible to themselves, their peers, and their teacher. Students and teacher can use this immediate feedback to guide modification and refinement in thinking [Bransford, 2000]. Students are encouraged to discuss questions with each other before, during and after the vote. If the voting result shows that most students did not answer correctly, then students participate in a “town meeting” discussion [Dykstra, 1992] to resolve the issue and a revote is taken. In our clicker methodology, the voting process uses a small additional percentage (typically 10%) of otherwise traditional lecture class time [Reay, 2008].

To measure the effectiveness of our clicker methodology, we make comparisons between lecture sections that used the clicker methodology (clicker sections) and others not using it (non-clicker sections). Other aspects of the courses, such as course content, homework, and recitation and laboratory sessions were kept the same for clicker and non-
clicker sections. Concept inventory tests and conceptual questions common to both sections’ examinations (quizzes, midterms, and finals) were used as measurement instruments.

We discovered that student performance on concept inventory tests greatly depends on the timing of the tests and incentives offered to students for taking the tests [Ding, 2008]. So, any positive gain observed might be a false positive unless these variables are controlled. To remove this uncertainty, we repeated our test in the introductory physics courses, controlling the timing and maximizing the incentives. However, we discovered that the statistically significant higher learning gain of the clicker sections decreased to a statistically non-significant higher learning gain when the timing was controlled and the incentives were maximized by making the posttest a part of the final exam for the course. We hypothesized that our previous practice of allowing students to review all course material except the clicker questions after the lecture was causing this. So we repeated our study with the timing controlled and the incentives maximized, but also giving students access to all the clicker questions online. All the clicker sections showed higher performance on conceptual questions than non-clicker sections.

We used conceptual multiple-choice questions as pre/post tests to measure students’ conceptual learning gains. For each course, there were two sections offered during the quarter: one section was taught using the clicker methodology in lecture and the other section was taught using the traditional passive lecture format. Administering the same pre/post tests to both sections and evaluating resulting learning gains using
pre/post conceptual tests showed that using clicker question sequences in lectures improved students’ conceptual learning gain.

The attendance rates for all the quarters show that clicker sections have higher attendance rate than non-clicker sections regardless of the types of incentives offered for using clickers. Students in clicker sections consistently rate highly of clickers in lecture. This is important because research has shown that students’ affective aspects can significantly influence their ability to learn or perform [Bandura, 1986]. We used end-of-course surveys to find out how students viewed the clicker methodology used in their courses. Most students ranked it highly and recommended it for use in other courses. Furthermore, many of the students believed that they were learning more and actively involved in their learning because of the clicker methodology.

This dissertation will present our clicker research within a framework developed out of what has been learned from interdisciplinary inquiries and scientific collaborations. This framework will be developed in Chapter 2. The development of clicker question sequence will be described in Chapter 3. The validation of clicker question sequences will be detailed in Chapter 4. How we used these question sequences in introductory physics courses will be discussed in Chapter 5. Results will be provided in Chapter 6. Chapter 7 will provide a summary of our clicker research which will conclude with the dissemination of all our clicker question sequences to many other institutions interested in using our clicker methodology.
CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

One of the hallmarks of the contemporary view of learning is that students construct new knowledge and understandings based on what they already know and believe [Bransford, 2000]. This perspective on learning comes from a theory of knowing called constructivism. Even though there are many varieties of constructivism [Ernest, 1995; Marshall, 1996; Phillips, 1995; Prawat, 1996], they all share the view that knowledge must be constructed and that new knowledge interacts with old knowledge. It must be noted that knowledge is constructed as the result of a learner’s active role in the construction process and knowledge constructed depends on preexisting knowledge. As reported by the Committee on Developments in the Science of Learning and the Committee on Learning Research and Educational Practice, important implications of this view are that an effective instructional methodology must both promote active learning and also address preexisting knowledge [Bransford, 2000].

In this chapter we will discuss various topics which guided our clicker research. We will begin by reviewing constructivism in Section 2.2. In Section 2.3, we will
discuss active learning. In Section 2.4, we will discuss preexisting knowledge. In Section 2.5, we will discuss lectures as traditional learning environment, and a PER-based modification to turn them into an active learning environment.

2.2 Constructivism

Constructivism is a theory of knowing. It deals with the nature of knowledge and the knowledge construction process. There are many varieties of constructivism [Ernest, 1995; Marshall, 1996; Phillips, 1995; Prawat, 1996] because of different viewpoints concerning nature of knowledge and the knowledge construction process. Moshman proposed three categories of constructivism according to its assumptions about the nature of knowledge and the knowledge construction process [Moshman, 1982]. The first type, exogenous constructivism, assumes that knowledge is accurate to the extent that it reflects the “way things really are” in the outside world and learners acquire knowledge by constructing an updated representation of the outside world [Woolfolk, 2007]. The second type, endogenous constructivism, assumes that knowledge is not a mirror of the external world, but rather an abstraction that grows more consistent with preexisting internal construction and organized with cognitive activities. Endogenous constructivism emphasizes knowledge construction that is directed by internal processes. The third type, dialectical constructivism, or social constructivism [Woolfolk, 2007], assumes that knowledge may or may not mirror the external world, depending on culture, language, beliefs, social interaction, and environment. Social constructivism emphasizes that knowledge is mutually built. But, the one common idea that binds them together is that
knowledge must be constructed. This implies that an effective instructional methodology must promote active learning [Bransford, 2000], which is discussed in the next section.

2.3 Active Learning

It is important to have a clear definition of what we mean by active learning. Active learning does not simply mean doing some activity while learning. For example, mechanically copying down what the instructor wrote on the board does not equal active learning. Instruction that requires some random activity also does not necessarily result in learning [Prawat, 1992]. One effective way to promote active learning is to build student participation directly into instructional methodology [Silberman, 1996]. For example, students can be asked to make a prediction on what would happen to a cart on a frictionless surface after a ball strikes it. Some portion of the learning process will always need to be done by individuals who spend time reflecting alone, but for most people, learning is most effectively carried out by engaging in dialogue with others [Fink, 2003].

Fink suggested a number of ways to promote active learning [Fink, 2003]. One method of engaging students in active learning is by stimulating a discussion through the use of questions. To make questions effective, they should be phrased clearly, adapted to the level of students’ abilities, asked logically and sequentially, and given with enough time for students to think.

These questions can be used as an immediate mastery test of the subject material covered, which would also promote active learning [Fink, 2003]. When students were
asked to take a test immediately after the subject was presented in lecture, they retained almost twice as much material as the students who did not take a test immediately after the lecture [Menges, 1988]. The test can be formative in nature [Bonwell, 1996]. A formative assessment is any evaluation of a student’s work that is not counted toward a course grade and is concerned with how to improve student learning using the information obtained as the result of the evaluation [Sadler, 1989]. Formative assessment with feedback is a central part of effective instructional strategy [Bransford, 2000]. Feedback provides information about the gap between the current level and the reference level, and can be used to alter the gap in some way [Ramaprasad, 1983]. Formative assessments, as sources of feedback, also permit the instructor to grasp students’ understanding and guide the instructional path accordingly. Feedback should be provided while it is still relevant [Crooks, 1988]. Immediate feedback was superior to delayed feedback for conceptual learning [Kulik, 1988; Bangert-Drowns, 1991]. Feedback is most valuable when students have the opportunity to use it to revise their thinking [Bransford, 2000], and it should be frequent [Crooks, 1988]. In-class discussions following feedback can provide such opportunities.

Active learning can be stimulated by using questions to provide formative assessment with immediate feedback, and then providing a platform for following student discussions. Questions can be made more effective by addressing preexisting student knowledge, which we will discuss in the next section.
2.4 Preexisting Knowledge

Preexisting knowledge can take various forms. It can consist of p-prims which are relatively minimal abstractions of simple common phenomena [diSessa, 1982, 1983]. For example, many students recognize the phenomenon that pushing an object off-center causes it to spin. This is a p-prim called “force as a spinner.” A good situation that cues this p-prim is shown in Figure 2.1. A yo-yo starts at rest as shown. When beginning students are asked which way the yo-yo would roll if someone pulls on the strings, using the “force as a spinner” p-prim, they would argue that the yo-yo would start to rotate counterclockwise. They would argue that yo-yo’s counterclockwise rotation would result in the yo-yo rolling away from the pull and roll toward the left. However, actually doing trying this experiment will show that that analysis is wrong; the yo-yo rolls toward the right.

Figure 2.1: A situation that cues the “force as a spinner” p-prim.
Preexisting knowledge can also be made up of bits and pieces of preconceptions, including misconceptions like those found by numerous researchers [Clement, 1982; Wandersee, 1994; Caramazza, 1981; McCloskey, 1980; Abimbola, 1988; Gilbert, 1985; Halloun, 1985a, b; McDermott, 1984, 1994; Peters, 1982; Champagne, 1980; Beichner, 1994; Viennot, 1979; Trowbridge, 1980, 1981; Cohen, 1983; Engelhardt, 2004; Eylon, 1990; Ambrose, 1999; Colin, 2001; Goldberg, 1986, 1987; Park, 2009]. It can also consist of mental models, which consists of propositions, images, rules of procedure and usage which may be contradictory and incomplete [Redish, 1994].

A note about the usage of the terms, “preconception” and “misconception,” is necessary. In the literature, many different terms are used to denote basically the same idea. Misconception, naïve theories or beliefs [Caramazza, 1981; McCloskey, 1980], alternative conception [Abimbola, 1988; Gilbert, 1985], common sense beliefs or concepts [Halloun, 1985b], erroneous ideas [Fisher, 1985], etc, are used to denote the concepts that students have before they start their first physics learning. However, in this paper, the term, “preconception,” will be used for all the concepts that the students constructed in their mind before they started their learning in physics. The term, “misconception,” will be used for preconceptions that contradict scientific concepts in physics. In other words, a misconception is a preconception that turns out to be incorrect when scientifically tested. This is necessary because some of the preconceptions that students have are actually correct and do not hinder the learning of physics.

The importance of addressing preconceptions, which can be used as building blocks in concept construction, can be illustrated using an example from a children’s storybook. In the storybook, a frog tells a little fish about the world outside of the water
that the fish lives in. When the frog tells the fish about a bird, the fish constructs the
concept of a bird as a fish with wings [Lionni, 1970] as in Figure 2.2. Similarly, students
may construct incorrect physics concepts using their preconceptions. So, it is important
to understand the initial states of students in introductory physics courses.

Figure 2.2: A conception of bird constructed by a little fish. Figure adapted from Fish is
A Fish [Lionni, 1970].

Fortunately, there is an extensive body of research on preconceptions.
Preconceptions frequently cut across age, ability, gender, and cultural boundaries
[Wandersee, 1994]. Research has documented preconceptions in classical mechanics
[Halloun, 1985a; Halloun, 1985b; McDermott, 1984, 1994; Clement, 1982; Caramazza,
1981; Peters, 1982; Champagne, 1980; Beichner, 1994; Viennot, 1979; Trowbridge,
1980, 1981], electricity [Cohen, 1983; Engelhardt, 2004; Eylon, 1990], optics [Ambrose,
1999; Colin, 2001; Goldberg, 1986, 1987], and various topics covered in modern physics
[Park, 2009]. For example, a common preconception in classical mechanics is the idea
that a body that has continuing motion implies the presence of a continuing force on the body in the same direction as its motion [Clement, 1982]. This preconception correctly correlates students’ observations at low velocities in a friction-dominated world [Redish, 1994]. However, this preconception interferes with the building of correct physics concepts and becomes a misconception that equates continuing motion with the presence of a continuing force even in frictionless environments.

In optics, an investigation of student understanding of the real image formed by a converging lens carried out by the Physics Education Group at the University of Washington showed that students who had not completed the optics portion of the college physics course had misconceptions about image formation by a converging lens [Goldberg, 1987]. One of the misconceptions found by their study concerned what happens to the image if some part of the lens surface was covered. A demonstration setup similar to the setup shown in Figure 2.3 was shown to the students. During their interviews and on their written questionnaires the students were asked to predict what would happen to the image visible on the screen if part of the lens were covered. The majority of the students had the misconception that half of the image would disappear if half of the lens was covered. Another misconception found was about the function of the screen. Again, most of the students had the misconception that an image can be seen on the screen no matter where it is placed, thus, as the screen was moved toward the lens, the image would remain clear with only its size changing. As the researchers noted, the students may have remembered from their experiences that the screen had to be moved further from the projector but did not also recall that it was necessary to refocus the projector as well.
Since misconceptions may be used as building blocks, instruction should attempt to confront them. Also, conceptual understanding form basic building blocks. Conceptual understanding is one of the key characteristics of experts which enable them to tackle new problems [Bransford, 2000]. Finally, a few fundamental concepts can explain a vast range of physics [Wieman, 2005]. Understanding them will allow students to tackle a broad range of physics problems. In the next section, we will discuss an example of how others have tried to create an active learning environment by posing questions as formative assessment with immediate feedback in lecture.
2.5 Lectures and Active Learning

Instruction can be defined as a process that produces a transition from some initial state to a final state of student capabilities [Reif, 1987]. Learning can be defined as a relatively permanent change in a student’s capabilities as a result of instruction [Woolfolk, 1987]. Effective physics instruction can be defined as instruction that produces a relatively permanent transition to a final state that is more similar to experts in physics [Wieman, 2005]. One cannot expect an introductory physics course to give student all the characteristics of experts, but one characteristic that should be stressed is conceptual understanding since they form the basic building blocks for physics knowledge construction.

However, traditional instruction is not optimal for teaching concepts [Arons, 1981; Peters, 1982]. Even for the few students that appeared to have learned these concepts, performance on conceptual tests indicated lack of functional conceptual understanding when different contexts are used [McDermott, 1993]. It may be that the appropriate concept is not activated because the student has learned that concept in another contextual situation [Whitehead, 1929] or a different context may activate different concepts [Pichert, 1977]. For example, when students were presented with two different situations, hands-on-spring and dictionary-on-hand, they were not able to use the concept of normal force correctly [Clement, 1989, 1993].

However, experts have both the concept and a specification of the contexts in which it is useful [Simon, 1980; Clement, 1989; Glaser, 1992]. They usually start with
fundamental concepts and know when specific concepts can be applied, while students rely more on surface features and look for equations [Chi, 1981; Chi, 1982].

One of the reasons that traditional instruction does not change students’ conceptual understanding to that of experts is that, by the time students take physics courses in high schools and/or in colleges, they have already developed a large number of intuitive preconceptions [Clement, 1982] that may produce difficulties in learning physics. Some of these preconceptions [Wandersee, 1994] are tenacious and resistant to extinction by conventional teaching strategies [Ausubel, 1978].

In traditional courses, students do not see conceptual change as the main function of the courses. Rather, about 73% of them view the main function as “transfer of facts” [Kowalski, 1987]. It is not surprising that students spend about 37% of the time in “passive thoughts about the subject” and “thoughts evidencing simple comprehension,” 31% of the time with irrelevant thoughts, and only 1% of the time attempting to solve problems and to synthesize (interrelate) information [Siegel 1963]. Also, traditional courses frequently don’t reduce students’ fear of appearing stupid when speaking in public, which increases their reluctance to participate. Communication in such courses is usually one-way. The lecturer transmits information and the students try to receive that information. Students are accustomed to listen and not talk, and formative assessment usually is not provided. “The students become members of a lecture audience and are reduced to little more than background” [Bloom, 1953]. Finally, concepts frequently are not displayed in multiple contexts.

Lecture, a major component of traditional introductory physics courses, is the most common instructional methodology used when teaching adults [Marris, 1964; Hale,
1964; Costin, 1972; Bowles, 1982; Karp, 1983; Nance, 1990; Gunzburger, 1993; Lesniak, 1996]. Some claim that lecture is “the most economical method by which the individual can present in a personalized and continuous argument the general framework for understanding the fundamentals of a particular subject, and involving the audience in reflective thought that moves in time with the on-going performance” [McLeish, 1976]. Others also claim that lecture is “economic of staff time” and “can cover more ground than a tutorial or seminar” [Hale, 1964].

The lecturer sets both the lecture’s pace and goals. Many faculty use lectures to transmit concepts, principles, facts, information, and technology, as well as to provide a framework [Bligh, 2000]. In doing so, most faculty believe that their lectures can accomplish these goals effectively. For example, 74% of the faculty believe that lectures could give important facts, 72% of them believe that lectures can explain difficult points, and 63% of them believe that lectures can provide a framework for private study [Isaacs, 1994]. Many faculty believe that lectures can achieve the ultimate goal of “development of enough knowledge in an area of science to allow intelligent study and observation to lead to subsequent learning without formal instruction” [Arons, 1990]. However, lectures do not require students to think [Taplin, 1969; Dunn, 1969]. Lectures also do not provide motivation for students to tackle the problems raised, as the lecturer does this for them [Bligh, 2000].

A landmark study carried out by Hake [Hake, 1998] showed that learning environments that promoted interactive-engagement produced higher conceptual learning gain than traditional courses. Hake defined interactive-engagement methods as those that promote conceptual understanding through interactive engagement of students in heads-
on and hands-on activities which yield immediate feedback through discussion with peers and/or instructors. Conceptual learning gains obtained by students in physics courses using different teaching methods are shown in Figure 2.4. His study involved about 6000 students and shows that most of the interactive-engagement courses produced significantly higher conceptual learning gain for students.

![Figure 2.4: Comparison of conceptual learning gains of interactive-engagement physics courses and traditional courses. [Hake, 1998.]](image)

Peer Instruction [Mazur, 1997] provides an excellent example of active learning that uses formative assessment with immediate feedback and discussions with peers and instructor. It is a widely adopted method that restructures the traditional lecture into a
series of short lecture presentations punctuated by a series of “ConcepTests” [Meltzer, 2002]. Students thereby focus their attention on underlying concept.

The Levi Straus trademark shows two horses trying to pull apart a pair of pants. Suppose Levi had only one horse and attached the other side of the pants to a fencepost. Using only one horse would: (a) cut the tension on the pants by one-half, (b) not change the tension on the pants at all, (c) double the tension on the pants?

Figure 2.5: A ConcepTest question. Figure adapted from ConcepTests [Meltzer, 2002].

A typical Peer Instruction lecture consists of a number of short presentations on key points, each followed by a ConcepTest. A ConcepTest is made up of short conceptual questions that probe students’ understanding of subject just being presented. An example of a ConcepTest is shown in Fig 2.5. Students are given a few minutes to come up with their individual answers and report their answers to the instructor. This report could be done by show-of-hands or showing flash cards, but now is done using in-class polling systems. Unlike the show-of-hands method to poll the class, clickers as in-class polling system allows students to participate anonymously and allows the teacher to get a rapid and accurate count of student votes. Students try to convince others of their own answers for about four minutes. Finally, a final poll is taken and the instructor
explains the correct answer to the students. The next short presentation of the lecture follows.

Instruction with effective active learning produces larger gains in students’ conceptual understanding than traditional physics courses [Beichner, 1999; Cummings, 1999; Hake, 1998; Johnson, 2001; Redish, 1997; Tobias, 1988]. Our clicker methodology stresses conceptual understanding and encourages students to conduct heads-on and hands-on classroom activities using clickers which lead to immediate feedback and discussion with peers and/or instructors. It is designed to turn traditional lectures into active learning environment that produces higher conceptual learning gains.
CHAPTER 3

SEQUENCE CREATION

3.1 Introduction

A major underlying hypothesis of our clicker research is that learning is context dependent. Situations that are isomorphic for experts may appear disparate to novices. To achieve broader understanding, students must view each concept embedded within a variety of surface features. This in turn motivates the use of question sequences for each concept, as opposed to single questions. Sequences mostly cover one concept, and consist of questions with different contexts. Each question is a multiple-choice question that if possible includes answer choices that represent known student misconceptions. These choices act as distracters. Succeeding questions are designed to provide formative assessment of the level of student understanding. Each sequence has been validated both by experts and beginning students, and has gone through years of actual in-class use at several colleges and universities. The validation process will be discussed in Chapter 4.

As of the writing of this dissertation, we have 61 Mechanics sequences (listed in Appendix A), 49 E & M sequences (listed in Appendix B), and 57 Waves, Optics, & Modern Physics sequences (listed in Appendix C). Most sequences contain 3 or 4
questions per sequence, though there are a few that contain 2 or 5 questions. In the following section we will describe various creation processes for the clicker question sequences.

3.2 Clicker Question Sequence Creation

Our clicker question sequences are created to cover topics taught in introductory physics courses. As we developed our clicker question sequences, three introductory physics textbooks [Cutnell, 2007; Halliday, 2005, 2008; Knight, 2004] were used at the Ohio State University. Three to five physics experts each made a list of concepts drawn from these textbooks and course syllabi to cover the one-year introductory physics courses. Their lists were combined to produce a master list of topics that our clicker question sequences should cover. These topics were standard materials covered in a typical introductory physics courses. Instructors teaching these courses at the Ohio State University and elsewhere were asked to report to us any concept not covered by our clicker question sequences. Their reports indicated no missing concepts for OSU course materials.

For some topics there existed extensive published work; for others, there was none. Existing research also was incorporated. (We focused on misconceptions and teaching techniques). If not, we created questions from textbooks, other lectures and our own imagination.

For each concept, we designed a multiple-choice question sequence using various sources to obtain ideas. These sources included the research literature, physics textbooks,
physics lectures, and week-long brainstorming sessions. Reviewing the research literature provided us with misconceptions and teaching tips that were incorporated into questions. Various textbooks, along with PER curriculum materials such as Peer Instruction [Mazur, 1997] and Tutorial in Introductory Physics also were consulted to provide guidance. Some ideas for questions were obtained from the lectures that we were observing. Frequently, we came up with our own questions by taking a week or so to brainstorm. These questions were validated together by the researchers and were expanded into an initial version of a question sequence.

3.2.1 Using Misconceptions As Distractors

One of the characteristics of a good multiple-choice question is that all distractors should be capable of distracting students [Kline, 1986]. Researchers in Physics Education Research have documented numerous student misconceptions in physics. We incorporated these misconceptions to act as distractors in our clicker question sequences.

As an example of question sequences that used common student misconceptions found in the research literature, we’ll use a mechanics question sequence on circular motion, shown in Figure 3.1. Circular motion is covered in the mechanics course and is considered to be a difficult concept for students to learn [Finley, 1982]. Literature reveals that students have misconceptions about circular motion [Gardner, 1984; Gunstone, 1984; McCloskey, 1980, 1983; Viennot, 1979; Warren, 1971]. We designed a four-question sequence to cover the concept of circular motion and used it in class during the Fall 2007 quarter. The first question, shown in Figure 3.1 (a), acts as a simple warm-
up that assesses students’ misconception that “circular motion at constant speed can be treated like rectilinear motion at constant speed” [Gardner, 1984]. The answer choice “1. No, because its speed is constant” acts as the distractor. Students who have the misconception that circular motion at constant speed can be treated like rectilinear motion at constant speed will chose the distractor as the correct answer to the question. About 16% of the students (28 out of 173) voted for the distractor.

Figure 3.1: First two questions of a Mechanics Clicker Question Sequence covering the concept of circular motion.
When students answer the second question, shown in Figure 3.1 (b), they will have learned that there is acceleration on the car. The second question provides a finer grained formative assessment of students’ understanding by providing various choices which include directions of forces similar to students’ misconceptions [Viennot, 1979]. About 13% of the students (23 out of 179 votes) picked one of the distractors, “7.” The 3rd and 4th questions can be found in Appendix A (Figure A.11 (c) and Figure A.11 (d), respectively).

### 3.2.2 Built-in Teaching Tips

For some concepts, other researchers have also provided suggestions and tips for teaching a particular concept more effectively. For example, one of the concepts covered in the Waves, Optics, & Modern Physics course is the concept of image formation by converging lens. Our question sequence shown in Figure 3.2 has incorporated various misconceptions [Goldberg, 1987], discussed in Chapter 2, as distractors. Additionally, the suggestion of using many rays, which is more effective in enabling students to overcome some of the misconceptions [Grayson, 1995], has been adapted in our question sequence, as done with the dotted red lines.
A lens is used to make an image; three light rays are drawn out of the infinite number coming from the arrowhead. The image given in this sketch could be seen:

![Sketch of light rays and image formation]

1. By placing a screen at the image point.
2. Without a screen by looking back at the lens.
3. By both techniques (1) and (2).
4. Only if the lens is big enough.
5. None of the above answers is 100% correct.

A screen is placed at the position of the image, and a “sharp” image appears on the screen. Next, Jennifer moves the screen a SHORT distance TOWARD the lens. The image would appear:

![Sketch of light rays with a screen]  
1. Smaller and “sharper”.
2. Smaller and “fuzzier”.
3. Larger and “sharper”.
4. Larger and “fuzzier”.
5. Would disappear.

Finally, Jennifer blocks half the lens, as shown, with a piece of paper: What happens to the image?

![Sketch of light rays with half of lens blocked by paper]  
1. It disappears.
2. Only half of it is still seen.
3. It looks the same, but gets slightly dimmer.
4. It gets fuzzy.
5. It depends on what part of the lens is blocked.

**Figure 3.2: Waves, Optics, & Modern Physics Clicker Question Sequence C20**
Figure 3.3: Mechanics Clicker Question Sequence A48
3.2.3 Physics Curriculum Materials As Sources

We also used published sources such as textbooks and PER curriculum such as Peer Instruction and Tutorial in Introductory Physics. A sequence that covers linear momentum is shown in Figure 3.3. The 2\textsuperscript{nd} question of sequence A48, shown in Figure 3.3 (b), is a conceptual question used in Peer Instruction, while the others (as shown in Figure 3.3 (a) and (c)) were created by us. The first question, shown in Figure 3.3 (a), acts as a simple warm-up that assesses students’ understanding of linear momentum conservation in one dimension. The second question, shown in Figure 3.3 (b), tests students’ understanding in a more complex situation. The third question, shown in Figure 3.3 (c), makes it a two-dimensional situation that requires the students to take into account the vector aspects of momentum as well.

3.2.4 Lecture Materials As Sources

As part of our clicker research, we observed traditional lectures given by other instructors. Some of our clicker question sequences were created from the questions these instructors used in their courses. For example, questions similar to those in our question sequence on Newton’s Third Law, shown in Figure 3.4, were used by Prof. Douglass Schumacher during one of his lectures and the questions were posed to students who answered the questions by raising their hands.
A metal ball is dropped and hits the ground. Just after the ball hits the ground and is still rapidly moving downward, what is the relationship between the magnitudes of the force $F_{BG}$ exerted on the ball by the ground and the force $F_{GB}$ exerted on the ground by the ball?

1. $F_{BG} > F_{GB}$
2. $F_{BG} < F_{GB}$
3. $F_{BG} = F_{GB}$
4. Can’t tell from the information given.

A metal ball is dropped and hits the ground. When the ball has penetrated well into the ground but hasn’t yet stopped, what is the relationship between the magnitudes of the force $F_{BG}$ exerted on the ball by the ground and the force $F_{GB}$ exerted on the ground by the ball?

1. $F_{BG} > F_{GB}$
2. $F_{BG} < F_{GB}$
3. $F_{BG} = F_{GB}$
4. Can’t tell from the information given.

A metal ball is dropped, hits the ground, and eventually comes to a stop. Now, what is the relationship between the magnitudes of the force $F_{BG}$ exerted on the ball by the ground and the force $F_{GB}$ exerted on the ground by the ball?

1. $F_{BG} > F_{GB}$
2. $F_{BG} < F_{GB}$
3. $F_{BG} = F_{GB}$
4. Can’t tell from the information given.

Figure 3.4: Mechanics Clicker Question Sequence A16
Each question in this sequence asks the students to first figure out the normal force acting on the dropped ball and use Newton’s Third Law to compare the forces exerted by the ball and the ground on each other. Though Newton’s 3rd Law guarantees that these forces are equal, student responses typically vary widely from question to question. Finally, they begin to grasp the meaning of the 3rd Law.

3.2.5 Brainstorming Sessions As Sources

For some concepts, there was no published research. One such concept is the concept of resolvability, which is taught in our Waves, Optics, and Modern Physics course. We created the sequence shown in Figure 3.5. The first question, shown in Figure 3.5 (a), is used to provide a graphical definition of resolvability. It makes a reference to headlights which many students would have experienced while driving. The second question, shown in Figure 3.5 (b), asks the students to use the equation for Rayleigh’s criterion for resolvability, $\theta_R = 1.22 \left( \frac{\lambda}{d} \right)$, to determine the resolvability of an event to which they can relate. The third question, shown in Figure 3.5 (c), asks the students to again use the equation to determine the resolvability of a similar event.
Figure 3.5: Waves, Optics, & Modern Physics Clicker Question Sequence C30
3.2.6 Formative Assessment By Each Question

Each succeeding question in our question sequences is designed to provide formative assessment of the level of student understanding. For example, each succeeding question of a sequence designed to probe students understanding of Lenz’s Law, shown in Figure 3.6, increases in difficulty or remains at a similar difficulty level as the previous one. As students answer each succeeding question, their responses indicate whether students have assimilated the concept.

The 1st question, shown in Figure 3.6 (a), assesses whether students understand that the induced EMF depends on the rate of change of flux. The 2nd question, shown in Figure 3.6 (b), allows a more detailed formative assessment of students’ understanding.

The last question, shown in Figure 3.6 (c), incorporates different contexts to assess students’ understanding of Lenz’s Law. A circular loop is used instead of a rectangular one, and the question involves graphs. Each question in the sequence can provide formative assessment for the instructor and students.

In the next chapter, we will describe how our question sequences were validated using physics experts, beginning students, and in-class use.
The figure shows two wire loops, with edge lengths of $L$ and $2L$, respectively. Both loops will move through a region of uniform magnetic field $B$ at the same constant velocity. Rank them according to the EMF induced \textit{just as their front edges enter the B field region}.

1. $a > b$
2. $a = b$
3. $a < b$
4. Depends on the magnitude of their common velocity
5. Depends on the magnitude of the $B$ field.

The figure shows four wire loops, with edge lengths of either $L$ or $2L$. All four loops will move through a region of uniform magnetic field $B$ at the same constant velocity. Rank them according to the EMF induced \textit{just as they enter the B field region}.

1. $a < b < d < c$
2. $a < b = d < c$
3. $a < b < c < d$
4. $a = b < c = d$
5. $a = b < d < c$

A circular wire loop moving at constant velocity enters a long region of uniform magnetic field $B$. Which one of the graphs describes the emf $\varepsilon$ in the loop as a function of time $t$?

1. $\varepsilon$
2. $\varepsilon$
3. $\varepsilon$
4. $\varepsilon$
5. $\varepsilon$

Figure 3.6: E&M Clicker Question Sequence B48
CHAPTER 4

VALIDATION

4.1 Introduction

From 2007 to 2009, we conducted a large-scale effort to validate the clicker question sequences that were created as discussed in the previous chapter. Our original plan had two parts. The first used a common validation practice that involves asking experts to examine if questions are technically correct, relevant, clearly stated, and cover major topics. The second part was to confirm introductory physics students understood questions after inclusion of corrections from experts. Our initial hypothesis was that most of the questions that went through the expert validation process would be of high quality and few additional changes would be required. About ten student interviews per sequence could be used to set a limit on the fraction of students in large lecture classes that might be led astray.

However, we quickly unearthed numerous examples of situations where students picked up validity issues missed by experts. Many questions that had gone through the expert validation process were not being interpreted in the same way by students. This was true even for question sequences that had received repeated cycles of expert
validation and/or in-class use. This completely changed the methodology used for student validation. Prompt changes to question sequences were made as the need was discovered and the revised version was then used during following interviews, instead of using the same unchanged version for students to review to collect statistics. We also invited and conducted multiple interviews with a select group of verbal and detail-oriented students that greatly aided us in finding issues missed by experts.

In Section 4.2, we will describe the expert validation. In Section 4.3, we will discuss student validation. In Section 4.4, we conclude this chapter by providing a summary of the final status of all our question sequences.

4.2 Expert Validation

A common validation practice used in physics education research involves soliciting expert opinions. For example, research-based multiple-choice assessment instruments in physics, such as the Brief Electricity and Magnetism Assessment (BEMA) [Ding, 2006], the Conceptual Survey of Electricity and Magnetism (CSEM) [Maloney, 2001], the Mechanics Diagnostic Test (MDT) [Halloun, 1985a], and the Test of Understanding Graphs in Kinematics (TUG-K) [Beichner, 1994] were validated by soliciting experts to review multiple choice questions. To validate BEMA, 8 faculty members who taught undergraduate E&M courses at Carnegie Mellon University were asked to critique the initial BEMA drafts [Ding, 2006]. The validity of the CSEM was established by asking 42 two-year college physics professors to rate using a 5-point scale [Maloney, 2001]. The MDT, which was the predecessor to the Force Concept Inventory
(FCI) [Hestenes, 1992], was validated by soliciting physics professors and graduate students to examine the early versions of the MDT [Halloun, 1985a]. The validation of the TUG-K also involved asking physics experts (15 science educators in high schools, community colleges, four-year colleges, and universities) to examine the TUG-K [Beichner, 1994].

For our study, we defined experts to be physics professors, physics post-doctoral researchers (post-docs), and physics graduate students. We assumed that experts can determine whether clicker question sequences are technically correct, relevant, clearly stated, and cover major topics taught in introductory physics courses. Initially, we also assumed that they can spot missing or misleading part(s) of question sequences that can prevent students from comprehending and interpreting the questions in the same way the experts would.

The expert validation process for our clicker question sequences involved 38 physics experts (35 graduate students, 2 post-docs, and 1 professor) for the Mechanics sequences, 10 experts (4 graduate students and 6 professors) for the E&M sequences, and 9 experts (7 graduate students and 2 professors) for the Waves, Optics, & Modern Physics sequences. The average number of experts that validated each sequence is 3.4 for Mechanics sequences, 3.2 for E&M sequences, and 2.6 for Waves, Optics, & Modern Physics sequences.

To obtain expert validation, we solicited for expert input in several ways. All the expert validation involving physics graduate students and post-docs was obtained using a survey form, shown in Figure 4.1. Each participant was given free food or a $10 gift card for reviewing 5 sequences.
<table>
<thead>
<tr>
<th>Question #</th>
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<td>10070004</td>
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</table>

Is the language of the question statement clear and appropriate?  
No | Yes | No | Yes |
---|---|---|---
1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5

If this question is accompanied by diagrams/graphs, do the diagrams/graphs precisely represent the physical situation(s) described in the question statement?  
No | Yes | No | Yes | No | Yes |
---|---|---|---|---|---
1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5

If not, please briefly describe what needs to be improved:  

Is the question physically correct? (correct physics)  
Yes | No | Yes | No | Yes | No |
---|---|---|---|---|---
1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5

If not, please specify the incorrect/imprecise physics contained in the question:  

Do the alternative choices cover common student errors?  
Yes | No | Yes | No | Yes | No |
---|---|---|---|---|---
1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5

If not, what other choices need to be added?:  

Are these questions logically related to each other to constitute a sensible sequence?  
Yes | No | Yes | No |
---|---|---|---
1 | 2 | 3 | 4 |

If not, please specify which question(s) is(are) logically irrelevant:  

Is the order of the questions sensible?  
Yes | No | Yes | No |
---|---|---|---
1 | 2 | 3 | 4 |

Do you suggest a different order? If yes, please describe your suggested order and provide brief descriptions of your reason(s):  

Figure 4.1: A survey form that physics experts (mainly graduate students and post-docs) used to rate clicker question sequences.
Figure 4.2: Instructor Question Sequence Survey

Each expert rated a set of about 5 sequences and provided additional written comments.

The surveys shown in Figure 4.1 asked them to rate each question according to its clear and correct use of language, diagrams, graphs, and physics, as well as viability of answer choices present. The survey also asked the experts to rate how well questions in a given sequence were interrelated and whether they were given in a sensible order. We used a 5-point Likert scale [Likert,1932] in which “1” represented a poor question and “5”
represented an excellent question. All the clicker question sequences received fairly high average ratings (> 4.0).

Figure 4.3: Instructor Question Sequence Survey (shorter version).

Chapter 14 - Oscillations

Q: How would you rate the usefulness of this question sequence relative to the learning goals that you have established for students in your course?

(unimportant) -2  -1  0  +1  +2  (important)

Q: Do you have any suggestions either for improving this sequence or constructing a better one?

Expert validations involving physics professors were obtained in two ways. The principal method was to ask the professors to fill out a survey form for each sequence they reviewed. Three different forms were used to customize the validation. The survey form shown in Figure 4.1, was used to obtain expert validation from a professor who did not have a teaching assignment for the year. Professors who provided expert validation on sequences as they used them in class used the survey form shown in Figure 4.2. A
shorter version, shown in Figure 4.3, was also used to obtain more rapid expert validation from a professor using the sequences in class.

The other method involved us reviewing computer files that contain actual classroom data. Professors teaching E&M courses were given all the sequences for their course and were free to use sequences in any way that they chose to do so. The use of a given sequence in class was an indication that the professor teaching the course approved it as a valid teaching material. This method was used only for the E&M sequences, which already had gone through years of classroom use and revisions [Li, 2007]. We reviewed the TurningPoint data files (which contained the lecture presentations and data on questions actually used and voted on by students during lecture) from 3 E&M courses offered at 3 different quarters at the Ohio State University. As can be seen in Table 4.1, only 7 E&M sequences were validated solely on classroom usage. These sequences were used by at least 2 professors, and are B1, B15, B23, B43, B45, B46, and B47, which can be found in Appendix B (B1 can be found in Figure B.1 and so on.).
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<th>Number of Expert Validation from Classroom Usage</th>
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Table 4.1: Expert Validation Using Surveys and Classroom Usage. The number of expert validation obtained from surveys and classroom usage is listed for the E&M sequences.
All survey forms filled out by physics experts were examined to see if sequences needed revisions. As we read written comments, we classified them into three categories: “significant,” “minor,” and “not accepted.” These categories will be explained and examples given in the following sections.

4.2.1 Expert Comments – Significant

A suggested change to a question sequence was classified as “significant” if the suggested change was one without which it was possible that a student might answer the question in a way that was different than what we had originally intended [Ding, 2009].

For example, expert comments indicated that the 2nd question, shown in Figure 4.4 (a), of sequence A7 should be changed to “distinguish A & C.” The unstated assumption of the question shown in Figure 4.4 (a) was that the deceleration was constant. So the original question was changed to the revised version shown in Figure 4.4 (b).
Figure 4.4: The 2nd question of the mechanics sequence A7. This is an example of a question that received a suggestion for change from physics experts that was considered a significant change. The question version shown in (a) was used for the expert validation. The version shown in (b) is the significantly changed version of the question. In response to the written comments, (“distinguish A & C: It needs to be assumed with constant accel.” and “for 2, which of A or C do you prefer?”), the question was changed and the phrase “at a constant rate of deceleration” was added as shown in (b).
Figure 4.5: The 2\textsuperscript{nd} question of the mechanics sequence A33. This is an example of a question that received a suggestion for change from physics experts that was considered a significant change. The question version shown in (a) was used for the expert validation. The version shown in (b) is the significantly changed version of the question. In response to the written comment, (“F, t not defined”), the changed version includes an explicit definition of F.
Another example is the 2nd question of the Mechanics sequence A33, shown both in its original version as used at the validation session in Figure 4.5 (a), and the significantly changed version, as shown in Figure 4.5 (b). In the original version, F is assumed to represent the gravitational force. However, comments from the physics expert validation survey indicated that F and t were nod defined. It should be explicitly stated that the gravitational force is represented by F. When the original version of the question, shown in Figure 4.5 (a), was given to a student during our student validation interviews, the student asked the interviewer what F was.

The last example of a significant change suggested by experts is the 2nd question of the Waves, Optics, & Modern Physics sequence C21. The expert reported that the 2nd question, shown in Figure 4.6, of the sequence was not clearly stated and the answers were not clear whether the movement was relative to some frame of reference. The phrase “dotted line through the book and perpendicular to the mirror” was added to the question and the answer choices referred to the dotted line.
Figure 4.6: The 2nd question of the Waves, Optics, & Modern Physics sequence C21.

This is an example of a question that received a suggestion for change from physics experts that was considered a significant change. The question version shown in (a) was used for the expert validation. The version shown in (b) is the significantly changed version of the question. In response to the comment that the question was not clearly stated, a statement regarding a “dotted line” was clearly stated in the question.
4.2.2 Expert Comments – Minor

A suggested change to the question sequence was classified as “minor” if the suggested change was one which improved the question but was not necessary for correct interpretation. To illustrate this, let’s look at some examples.

Mechanics sequence A2 contained the question, shown in Figure 4.7 (a), which was given to the physics experts. The suggestion that the word “meter” in Figure 4.7 (a) should be changed to either “meters” or “m” was categorized as “minor.” The changes were made to the question as shown in Figure 4.7 (b). However, this change is not significant because it did not prevent students from understanding the question.
Figure 4.7: The 3rd question of the mechanics sequence A2. This is an example of a question that received a suggestion for change from physics experts that was categorized as “minor.” The question version shown in (a) was used at the validation session. The version shown in (b) is the revised version of the question. In response to the written comment, (“switch ‘meter’ to ‘m’ or ‘meters’ in answer choices”), this change was made.
Figure 4.8: The 1st question of the E&M sequence B18. This is an example of a question that received a suggestion for minor change from a physics instructor. The question version shown in (a) was used for the expert validation. The version shown in (b) is the modified version of the question. In response to the written comment, (“remove arrow head for clarity”), the question was changed to the modified version of the question shown in (b).
Another sequence that received suggestions that were “minor” was E&M sequence B18. Figure 4.8 (a) shows the original version reviewed by an expert and Figure 4.8 (b) shows the modified version. In addition to the expert suggestion, “remove arrow head for clarity,” the question was further changed to make it clearer that the test charge is a negative charge and is at rest before and after the move. Also, the phrase in the original version, “How much work was done to the test charge,” was changed to “How much work was done by the net external force while moving the test charge from A to B.”

An additional sequence that received suggestions that were “minor” was Waves, Optics, & Modern Physics sequence C19. Figure 4.9 (a) shows the original version reviewed by experts and Figure 4.9 (b) shows the modified version. One of the experts pointed out that there was “some issue with the discontinuity of the string at the wall” for answer choices “1” and “3” as shown in Figure 4.9 (a). The fact that the string is tied to the walls was made clearer by representing the points of attachment by half-circles. The presence of rope between the pulse and the point of attachment for answer choices “1” and “3” were made visible.
Figure 4.9: The 2\textsuperscript{nd} question of the Waves, Optics, & Modern Physics sequence C19.

This is an example of a question that received a suggestion for minor change from a physics instructor. The question version shown in (a) was used for the expert validation. The version shown in (b) is the modified version of the question.
4.2.3 Expert Comments – Not Accepted

A suggested change to the question sequence was classified as “not accepted” when, in our judgment, the change would not improve the question. For example, an expert commented that “Man A is in a funny position” for Mechanics sequence A23, shown in Figure A.23 (in Appendix A). Even though it would require great strength to hold a position similar to Man A in Figure 4.10, it was not necessary to redraw the stick-figure for Man A. So this comment was not made into a change to the sequence.

Figure 4.10: The 1st question of Mechanics sequence A23. An expert commented that Man A is in a “funny position,” but no change was made and the comment was categorized as “not accepted.”
Another example of expert suggestion that was “not accepted” was for E&M sequence B30. An expert suggested that the arrows representing currents, shown in Figure 4.11, are drawn bigger. However, with the space available for the question, making the arrows bigger would crowd the circuit diagram too much. Therefore, this suggestion was “not accepted.”

Which of the following equations gives the correct Kirchhoff loop rule starting at point b and proceeding clockwise through batteries $\varepsilon_1$ and $\varepsilon_2$ and back to b?

1. $i_1 R_1 + \varepsilon_1 - \varepsilon_2 - i_2 R_2 = 0$
2. $-i_1 R_1 - \varepsilon_1 + \varepsilon_2 + i_2 R_2 = 0$
3. $i_1 R_1 + \varepsilon_1 - \varepsilon_2 + i_2 R_2 = 0$
4. $i_1 R_1 - \varepsilon_1 + \varepsilon_2 + i_2 R_2 = 0$
5. $-i_1 R_1 + \varepsilon_1 - \varepsilon_2 + i_2 R_2 = 0$

Figure 4.11: The 2nd question of E&M sequence B30. Arrows indicating the current were not made bigger as suggested by an expert. (The space under the circuit diagram is reserved for TurningPoint objects.)

Another expert suggested that a coordinate system should be added to Waves, Optics, & Modern Physics sequence C32. However, this suggestion was “not accepted” since the parallel lines on the polarizers, as shown in Figure 4.12, did the job.
Figure 4.12: The 3rd question of Waves, Optics, & Modern Physics sequence C32.

Table 4.2 provides a summary of the total number of “significant,” “minor,” and “not accepted” changes suggested by physics experts. Table 4.3 provides a sequence-by-sequence summary.

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<td>Total (N = 167)</td>
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Table 4.2: Number of Expert Suggested Changes To Question Sequences.
Table 4.3: Types of Changes Suggested for Each Sequence.

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4.3 Student Validation

As previously mentioned, our original hypothesis was that expert validated question sequences usually would not require additional significant changes based on student interviews. Student interviews for the most part would be conducted to get statistical confirmation that the sequences indeed are good for use with large numbers of introductory physics students.

In order to calculate the minimum number of students we needed for our student validation interviews, let’s assume that a large lecture consists of two types of students: those who understand the sequence (“U” students) and those that do not (“D” students). Let \( u \) be the number of “U” students and \( d \) be the number of “D” students. Let \( N \) be the total number of students in lecture \( (N = u + d) \).

The probability \( P(1) \) of selecting an “U” student at random from a group of \( N \) students is

\[
P(1) = \frac{(N - d)}{N}.
\]

The probability \( P(2) \) of selecting another “U” student at random from a group of remaining \( (N - 1) \) students is

\[
P(2) = \frac{(N - d - 1)}{(N - 1)}.
\]
The probability \( P(n) \) of selecting an “U” student at random from a group of remaining \((N - (n - 1))\) students is

\[
P(n) = \frac{(N - d - (n - 1))}{(N - (n - 1))}.
\]

The probability \( P(“all U“) \) of selecting \( m \) students at random from \( N \) students and all of the \( m \) selected students being “U” students is

\[
P(“all U“) = \frac{(N - d)! (N - m)!}{(N - d - m)! N!}.
\]

Then the probability \( P \) that a randomly selected group of \( m \) students has at least one “D” student is

\[
P = 1 - P(“all U“) = 1 - \frac{(N - d)! (N - m)!}{(N - d - m)! N!}.
\]

Using this equation with \( N = 215 \) (a typical size at OSU), the graph shown in Figure 4.13 shows the minimum number of students that needs to be selected to have an 80%, 90%, or 95% chance of having at least one student who does not comprehend or interpret correctly in the selected group. For example, the 80% line indicates that, for a lecture with 15% “D” students, there is an 80% chance that a group of 10 randomly selected students will have at least one “D” student. This was the number of students that we
could handle for the interviews, and was the minimum number of students that we initially wanted to review each question sequence.

Figure 4.13: The minimum number of interviewed students required to have an 80%, 90%, or 95% chance of selecting at least one student who does not understand.

We began our student validation by recruiting students taking the traditional introductory physics courses (non-clicker section) at OSU during Fall 2007. We recruited students from the non-clicker section to ensure that they had not previously seen question sequences. The incentives offered for participating in the one-hour one-to-one interview were a $10 gift card and free physics tutoring after the interview. Their participation was kept confidential and was not made known to their instructor.
Approximately 20% of the students signed up but only about 50% of those signed up actually came to the interview sessions. For the 2007 Mechanics interview, 24 students participated. All students were interviewed after they had covered the same relevant material in their own classrooms.

Each student interviewee was pre-trained in the use of the talk-aloud protocol during a briefing before their first interview. Students were given one question at a time to read it, and were asked to comment on its clarity. Students were also asked to rephrase the question without answering it, evaluate the accuracy of the language, and report any graphical misrepresentations. Then, we asked students to attempt to work through the question. As students attempted to answer questions, they were asked to think aloud and voice any confusion they encounter. As they worked through the question, they wrote directly on the question sheet. When students finished all the questions in a sequence, all the questions in the sequence were presented as a set and students commented on what ties them together. Interviews were video recorded using two video cameras, one recorded what the students were writing on the question sheet and the other recorded the student. Interview videos were repeatedly viewed by researchers and transcribed as deemed necessary.

During the interview, care was taken so that the process of trying to find out, or probing, what is going through student’s mind did not itself cause distortion. For example, if a student is asked to explain what one is doing while doing it, this places a big burden on attentional capacity because he/she has to attend to two complex tasks at the same time [Gagne, 1993]. This heavy demand on attentional capacity may cause the
student to use different strategies than the ones that would be used when there was no demand to explain.

The “thinking aloud” method has been used by Gestalt psychologists to study human problem-solving behaviors. K. Duncker studied human problem solving by requiring subjects to think aloud as they attempted to solve a problem [Duncker, 1945]. The thinking aloud method helped to trace the reasoning processes, or cognitive states, that subjects generated on their way toward a solution [Dellarosa, 1988].

Research has shown that both the “thinking aloud” method and the “retrospective reports” are valid types of verbal reports that are reliable and can be used as scientific data [Ericsson, 1980]. In the thinking aloud method, students simply report what they are thinking, rather than being required to explain how they are thinking. Reporting demands little attention and, therefore, does not disrupt the main task [Gagne, 1993]. A retrospective report is another valid form if the report is given immediately after the task is completed [Ericsson, 1980]. One example of the thinking aloud method used in physics education research is a study done by Larkin and her colleagues [Larkin, 1980]. In their study, novices and expert physicists were asked to think aloud while they solved a physics problem involving a moving body on an inclined plane with friction. Their research showed that expert physicists follow a “working-forward” path while novices follow a “working-backward” path.

The practice of “showing your work” is another valid method to probe student understanding. It is similar to the thinking aloud method, except that one writes rather than speak one’s thoughts aloud. The showing your work method can also reveal
incorrect mental operations and deeper misconceptions [Gagne, 1993]. From what students wrote down, we were able to detect student confusion that was not verbalized.

At each interview session, students typically were able to work through 3 sequences. For each student interviewee, we first used question sequences which covered the most recent topics covered in lecture. Typically, we used question sequences that had just been used in the clicker lecture section. We did not present them with question sequences that covered topics not yet covered in lecture.

As we conducted student interviews, it became clear that student interviews identified many validity issues missed by experts. Therefore, we made two changes to student interviews so that we could maximize their efficiency. The first was to make prompt changes to question sequences as the need was discovered, rather than continue to have additional students review the same version of a sequence and collect statistics. The revised version was then used during following interviews.

The second change was to utilize a select group of students that greatly aided us in finding changes missed by experts. During the course of student interviews, we noticed that several students were verbal and detail-oriented, and were pointing out numerous valid and significant items. We conducted multiple interviews with these students, who became increasingly accustomed to the procedure and more sensitive to potential validity issues. We were able to work with 11 student experts (2 female) for Mechanics, 8 student experts (2 female) for E&M, and 6 student experts (2 female) for Waves, Optics, & Modern Physics.

Two aspects about these student experts are worth mentioning. First, they were explicitly invited to return for multiple interviews as consultants rather than mere test...
takers. Their comfort level was high and their interest in participation was surprising high. Some even wanted to come in for an interview after their final exams. Another interesting aspect is that most of these student experts came from the upper half of the class. Though initially not selected on the basis of grades, they had an average final course grade of B+ in their Mechanics course. (There was one student expert who received a D+ in the course, while others received A’s, B’s and C’s.) This finding is consistent with Tao’s observations [Tao, 1992], in which he argues that high-achieving students are more likely to recognize deep structures and have a greater capability to detect missing and irrelevant information within physics problems.

The average number of student interviews conducted to validate the sequences is 4.5 (3.5 with student experts) for Mechanics, 5.3 (3.9 with student experts) for E&M, and 2.7 (2.7 with student experts) for Waves, Optics, & Modern Physics.

Contrary to our initial hypothesis, many expert-validated questions required additional modification based on student interviews. We discovered this initially when we conducted our student interviews in Fall 2007. As we continued our research with students in Mechanics, E&M, and Waves, Optics, & Modern Physics courses from 2007 to 2009, we continued to discover that many expert-validated question sequences required modification based on student interviews. These student interview motivated modifications were categorized into “significant” and “minor” as was done for the expert suggested changes, which was discussed in the previous section.
4.3.1 Student Changes – Significant

An example of significant change motivated by student interviews is Mechanics sequence A11. It had to undergo significant changes after student interviews despite the fact the physics experts did not require any significant change. Figure 4.14 shows different versions of the 2nd question of the sequence A11. 5 physics experts reviewed the original version, shown in Figure 4.14 (a), and suggested that an arrow be put in the diagram to indicate that the car is moving. This suggested change was “minor.” The resulting modification can be seen in the revised version, shown in Figure 4.14 (b).

However, when the revised version, shown in Figure 4.14 (b), was shown to a student during the student interview, the student interpreted the question in a way that was quite different from the original intention of the question designers. The student chose the answer choice 9, “Zero Net Force,” as his choice because he noted that “it would zero net force… if I added up all these forces…. ” The student drew correct instantaneous forces, but interpreted the phrase “net force” as the time-averaged force. In order to eliminate this possible confusion, we added the phrase “at the instant shown” to the question, shown in Figure 4.14 (c).
Figure 4.14: A sequence that underwent a significant change because of the student interviews.
E&M sequence B12 also required a significant change. A student expert pointed out that the original version of the 1st question of the sequence, shown in Figure 4.15 (a), should be changed to “what’s the net charge inside the box”. This change was significant because the student expert knew the concept correctly but was hesitating between choices “1. Positive” and “4. Cannot be determined” because it was possible to “have some negative charges in the box… as long as the net charge is positive”. So we added the word “net” as shown in 4.15 (b).

Waves, Optics, & Modern Physics sequence C8 required a significant change. A student expert interview identified that the phrase “after 1.5 seconds” in the 1st question of the sequence, shown in Figure 4.16 (a), needed to be changed since “after 1.5 seconds” refers to all time after 1.5 seconds. The question was changed to clearly indicate the answer should be what the wave would look at $t = 1.5$ seconds, as in Figure 4.16 (b).
Figure 4.15: The 1st question of the E&M sequence B12. The original version is shown in (a). The question version shown in (b) is the significantly changed version.
A transverse wave is traveling to the right with velocity 2m/s and wave length 4m. What will the wave look like after 1.5 seconds?

A transverse wave is traveling to the right with velocity 2m/s and wave length 4m. What will the wave (shown on the right, at t = 0 sec.) look like at t = 1.5 seconds?

Figure 4.16: The 1st question of Waves, Optics, & Modern Physics sequence C8. The original version is shown in (a). The question version shown in (b) is the significantly changed version.
4.3.2 Student Changes – Minor

Student interviews also motivated changes that were “minor.” For example, student interviews revealed that the original version of the sequence A60/61 required a minor change. A student pointed out that the symbol used for speed in the 1st question, shown in Figure 4.17 (a), should be “v” rather than “V”. This suggestion was used to change the question to the version shown in Figure 4.17 (b).

An example of an E&M sequence that needed “minor” changes is shown in Figure 4.18. A student noted that it would be clearer to change the phrase “left-hand(red) charge” in Figure 4.18 (a) to something like “charge represented by a red circle” as is done in Figure 4.18 (b).

A student expert suggested a change to Waves, Optics, & Modern Physics sequence C31 which was “minor.” The student suggested that coloring is added to the cloth in the diagram, shown in Figure 4.19 (a), to make it clearer. This suggestion was made into the revised version, shown in Figure 4.19 (b).

Table 4.4 provides a summary of the total number of “significant” and “minor” changes motivated by student interviews. Table 4.5 provides a sequence-by-sequence summary.
Figure 4.17: The 1st question of the mechanics sequence A60/61. It is an example of a question that received a suggestion for minor change from student interviews. The question version shown in (a) was used at the expert validation session. The version shown in (b) is the changed version of the question as the result of student interviews. A student mentioned that the symbol for speed should be “v” rather than “V”. This suggestion was made into the revised version as shown in (b).
Figure 4.18: A sequence that underwent a minor change because of student interviews.
Figure 4.19: The 2nd question of Waves, Optics, & Modern Physics Clicker Questions sequence C31.

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Continued

Table 4.5: Types of Changes Motivated by the Student Interviews for Each Sequence.
Table 4.5 continued

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Continued
Table 4.5 continued

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<tr>
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4.4 Discussion

As discussed previously, physics experts provided a check on whether the clicker question sequences were technically correct, relevant, clearly stated, and cover major topics. They suggested significant and minor changes to our sequences, as shown in Table 4.2. Overall, experts suggested significant changes for 9 (5%) of the 167 sequences and minor changes for 46 (28%) sequences.

However, as we have seen earlier in this chapter, there were many issues that experts missed that students identified. As Table 4.4 shows, student interviews helped to identify validity issues missed by experts for 81 (49%) of the 167 sequences, and 18 (11%) of them were significant. Thus, a large fraction of sequences required modifications in addition to experts’ suggested changes. Why, then, would physics experts miss these issues? One of the possibilities why experts may miss validity issues that students identify is that experts tend to ignore irrelevant information and fill in missing information. However, for the students, this is not an automatic task. Consequently, students may perceive the questions differently than physics experts.

Because of this finding, we believe that an effective clicker question sequence validation requires inputs from both experts and students. Experts should play the role of evaluating the technical correctness, relevance, and the coverage of the question sequences for the introductory physics courses. Beginning physics students should play the role of pointing out issues that experts tend to automatically fill in or ignore, which may hinder or prevent students from correctly comprehending and interpreting the question sequences.
Based on these findings, we now have 61 Mechanics sequences, 49 E&M sequences, and 57 Waves, Optics & Modern Physics sequences that have been validated by experts and students. The final version of these sequences are shown in Appendix A, B, and C for Mechanics, E&M, and Waves, Optics, & Modern Physics, respectively. The sequence number (e.g. B22) corresponds to the figure number in the Appendix (e.g. Appendix B, Figure B.22). These research-based sequences have been and will be distributed to others at various workshops and will mark the completion of our clicker project.

In the next chapter, we will describe how these sequences were used in class to promote active learning that resulted in higher conceptual understanding for the section that used the clicker methodology (clicker section) compared to the traditional section (non-clicker section).
5.1 Introduction

Many large universities make extensive use of passive traditional lectures, which are cost effective but not learning efficient. As discussed previously, education research has shown that students learn more when actively involved in the process. In-class polling systems can add an active learning component to passive lectures, provided questions are properly designed. In Chapter 3 and Chapter 4, we described how we designed and validated the question sequences, respectively. In this chapter, we will discuss how we use properly designed question sequences with an in-class polling system to create an active learning environment.

An in-class polling system can be used by students to answer multiple-choice questions projected for audience viewing as PowerPoint or similar presentations. A response summary is created in real time, and may be shown to students at the lecturer’s discretion. Most lecturers use both questions and response summaries as a basis for creating discussion.
Researchers use a variety of names for in-class polling systems, such as “Group Process Support System” [Jones, 2001], “Classroom Communication Systems” [Nicol, 2003], “Classroom Response System” [James, 2006], “Voting Machines” [Reay, 2005], “Electronic Voting System,” “Audience Response System,” and clickers [Knight, 2005]. In-class polling systems have been used and studied in many different areas such as logic lectures in the philosophy department [Stuart, 2004], seminars in the business department [Jones, 2001], introductory programming courses in the computer science department [Kennedy, 2005], microeconomics principles lectures in the economics department [Elliott, 2003], molecular, cellular and developmental biology department [Knight, 2005], and in introductory physics lectures in a physics department [Reay, 2005].

A decade ago, clickers were expensive and frequently unreliable “one-way” devices. Clickers could talk to the receiver, but the receiver could not reply that a student’s answer had been received. Advancement of computer and related technologies have resulted in “two-way” response systems from several companies that are Radio-Frequency-based, reliable, inexpensive, receive responses from thousands of students over distances of several hundred feet, and communicate back to student handhelds when votes are received. These include Classtalk [Dufresne, 1996], Personal Response Systems (http://www.educue.com), Fleetwood Systems (http://www.replysystems.com), iClicker (www.iclicker.com), and TurningPoint (http://www.turningtechnologies.com/). All of the above have software for recording and processing student votes.

In this chapter, we will describe in detail how we used our clicker question sequences in the lecture sessions of the introductory physics courses offered at the Ohio State University.
Figure 5.1 A hand-held clicker, ResponseCard RF, from Turning Technologies.

5.2 Description of In-Class Polling System Used

For our study, we used a commercial in-class polling system product from Turning Technologies. The system consists of a radio-frequency receiver, hand-held radio-frequency clickers, and the TurningPoint software. The TurningPoint software is an add-on to PowerPoint presentation software from Microsoft. Each student uses a hand-held clicker, shown in Figure 5.1, to answer questions shown as PowerPoint slides. (The receiver, shown in Figure 5.2, provides a wireless radio-frequency link between the TurningPoint software and students’ clickers.) TurningPoint software then processes all the data and summarizes student responses.

Figure 5.2 A receiver, RF Receiver (Radio-Frequency), from Turning Technologies.
5.2.1 Distribution of Clickers to Students

Previous experiences with different ways of distributing clickers to students prompted us to distribute and collect the clickers at every lecture session. Each student was assigned a specific clicker for the course. As students entered the lecture hall, they picked their assigned clickers from clicker boards placed near the two entrances to the lecture hall. A typical clicker board which holds 50 clickers is shown in Figure 5.3. Velcro (black strips in Figure 5.3) was used to make it easy to take the clickers off and put them back on the board. Clickers (#1 - #100) were placed near one entrance and the rest were placed near the other entrance.

This placement of the clicker boards worked well for classes with as small as 50 and as large as 215 students. There are 12 minutes between classes, and the rate at which students enter the lecture hall is reasonably constant in time. Figure 5.4 shows the pattern of student entry into the lecture hall for the clicker section during the E&M course offered during Spring 2007 which was typical for all the courses. Some students came into the lecture hall an hour early when the hall was not being used by another course.
Figure 5.3  A clicker board holding 50 clickers for in-class distribution to students.
Figure 5.4: Student attendance as a function of class time (in minutes) for 8:30am E&M clicker section during 2007 Spring Quarter.

Figure 5.5 shows the student entry for the non-clicker section. Comparing the entry rate between $t = -10$ minutes (10 minutes before class starts) and $t=0$ (when the class starts) shows that requiring students to pick up their clickers at every lecture does not unpredictably delay entering clicker students. Clicker students were able to return their clickers to the clicker boards and leave the lecture hall within 5 – 10 minutes, which allowed students in other classes to enter the lecture hall without much hassle.
Figure 5.5: Student attendance as a function of class time (in minutes) for 9:30am E&M non-clicker section during 2007 Spring Quarter.

Figure 5.6 shows that a large fraction of the students who attend the lectures pick up their clickers. The average attendance rate of enrolled students in the clicker section was 80% during our comparison tests (compared to 65% for the non-clicker sections). About 96% of the students who came to the lecture picked up their clickers. Some students normally do not pick up their clickers even when gently reminded. However, when we asked students to vote on whether to change the format of the quiz, several students came back to the clicker board and picked up their clickers to cast their votes.
One student said, “I gotta vote on this.” We observed that students who are late to class tend not to pick up their clickers.

![Figure 5.6: Percentage of attending students who picked up clickers.](image)

Figure 5.6: Percentage of attending students who picked up clickers.

Passing out the clickers and collecting them allowed us to periodically check units. We checked that each clicker was able to send data and was being recognized by the system. This check was done every two weeks in the lecture hall before class and resulted in very little need to reset a clicker. From 2007 to 2009, there were 8 out of 250 clickers had to be replaced due to broken buttons and less than 1% that had to be reset.
This involved pressing 4 button combinations to reset the radio frequency used to communicate with the receiver. If a student pressed the “Go” button followed by any 2 number buttons and end with the “Go” button, the radio frequency would be changed to a value not recognized by TurningPoint software.

Occasionally, students picked up more than one clicker as they came in. Some of these were picked up for their peers who came to the lecture later, and seemed to be used by the appropriate students. However, we observed some students using multiple clickers, perhaps to vote for someone who was not present in the lecture hall. This phenomenon seemed to happen more frequently as the incentives for using the clickers were increased. For example, in 2008 Fall Mechanics course, students were given 4% bonus points if they answered at least 30 clicker questions correctly and the number of clickers picked up frequently exceeded the number of students attending as shown in Figure 5.6. (As an example, during Fall 2008, there were 140 students attending the 18th lecture, but 144 clickers were picked up.) This seems to be due to the fact that there was more incentives for answering the clicker question sequences compared to, say, 2008 Winter E&M course, which had no bonus point for using clickers.

Anecdotally, we also recognized several non-clicker students attending the clicker lectures. Some attended both the clicker and non-clicker sections.

5.3 Using the OSU Clicker Question Sequences in Lecture

One or two clicker question sequences are used in a typical 48-minute lecture. After the instructor goes over a topic, a question sequence on the same topic is used to
promote active learning. For each question of the sequence, students are presented with the question via the display at the front of the lecture hall, students select their answer choices using clickers, students see how the class voted, and students discuss their selections. Depending on how students voted, students revote on the question and the cycle is repeated. Frequently, the first question is less challenging and is correctly answered so the discussion is typically brief. Students are presented with the next question and the cycle is repeated. The final question is used to check whether the students understood the concept. We will use an example from an E&M course to illustrate how the question sequences are used in lecture sessions.

Figure 5.7: A PowerPoint slide used to teach Lenz’s Law.

The instructor began the lecture by going over Lenz’s Law using a PowerPoint slide, shown in Figure 5.7, and the blackboard. Once the topic was covered, the 1st question, shown in Figure 5.8, of the sequence on Lenz’s Law was shown on the display.
The figure shows two wire loops, with edge lengths of L and 2L, respectively. Both loops will move through a region of uniform magnetic field $B$ at the same constant velocity. Rank them according to the EMF induced just as their front edges enter the B field region.

1. a>b
2. a=b
3. a<b
4. Depends on the magnitude of their common velocity
5. Depends on the magnitude of the B field.

Figure 5.8: 1st question of an E&M sequence on Lenz’s Law.

This question sequence addresses the difficulty students have differentiating magnetic flux and the rate of change of magnetic flux. Others have found that students mistakenly connect larger induced EMF to larger loops rather than to the rate of change of magnetic flux in a loop [Maloney, 2001]. The instructor read the question aloud and clarified it further if needed. The instructor typically waited until approximately 2/3 of the students vote to start the countdown. We have set the countdown to be 40 seconds.

When the voting ends, TurningPoint software creates a histogram of how many students selected each answer choice. Most students may select the correct choice, or a variety of answers may be selected. No matter what the outcome, it is important to have
some discussion before proceeding forward. Student surveys indicate that students may select the same answers as the better students without fully understanding why. If almost every student selects the correct answer, as shown in Figure 5.9, a brief discussion by the instructor frequently suffices.

Figure 5.9: A histogram showing that most students picked the correct choice, “3”. 98% of students (2007 Spring) selected the correct choice.

However, if many answers are selected, as in Figure 5.10, it becomes important to generate class-wide discussions, frequently followed by a revote on the same question.
The figure shows two wire loops, with edge lengths of L and 2L, respectively. Both loops will move through a region of uniform magnetic field $B$ at the same constant velocity. Rank them according to the EMF induced just as their front edges enter the $B$ field region.

1. $a>b$
2. $a=b$
3. $a<b$
4. Depends on the magnitude of their common velocity
5. Depends on the magnitude of the $B$ field.

Figure 5.10: A histogram showing that most students did not select the correct choice, “3”. Students (2007 Spring) selected many answers, so class-wide discussions were generated and a revote was taken.

On the first question, shown in Figure 5.8, some could have chosen the correct answer using the rate of change of flux, but others could have reasoned that wire loop “b” has bigger total area and therefore a larger induced EMF. Before moving onto the next question in the sequence, the instructor clearly pointed out what the correct answer was and offered a summarizing explanation.

But if the histogram shows that most students did not select the correct choice, then the instructor asks for student volunteers to offer possible explanations for each answer choices. After students listen to various possible explanations for each answer
choices, students are encouraged to discuss with each other and submit their answer choices for the revote on the same question. Generally, the volume level goes way up and when it subsides, the instructor can start the 40-second countdown for the revote. Our experience at OSU indicates that most students migrate to the correct choice in the revote, but this is not always the case. The instructor then needs to rely on other methods, such as using different examples, to clarify the concept.

The figure shows four wire loops, with edge lengths of either L or 2L. All four loops will move through a region of uniform magnetic field \( B \) at the same constant velocity. Rank them according to the EMF induced *just as they enter the B field region*.

![Diagram of four wire loops with edge lengths of either L or 2L.](image)

- 1. \( a<b<d<c \)
- 2. \( a<b=d<c \)
- 3. \( a<b<c<d \)
- 4. \( a=b<c=d \)
- 5. \( a=b<d<c \)

Figure 5.11: The 2\textsuperscript{nd} question of an E&M sequence on Lenz’s Law.

Next, the instructor read the 2\textsuperscript{nd} question, shown in Figure 5.11, aloud and provided clarification if needed. This question purposefully has two loops with the same total area (loop “b” and “d”) but oriented differently so that the rate of change would be
different. This question assesses whether the students really understood that the induced EMF depends on the rate of change, not the size of the loop. The instructor waits until approximately 2/3 of the students vote to start the 40-second countdown.

The instructor repeats the same cycle used for the 1st question. This cycle allows the instructor to assess whether the students understand the concept. Students can also assess their own understanding by the immediate feedback available through the in-class polling system.

Figure 5.12: The 3rd question of an E&M sequence on Lenz’s Law.

The last question of the sequence acts as the final check for the instructor and the students. The 3rd question of the sequence on Lenz’s Law is shown in Figure 5.12. This
question has a different context than the first two questions in that the loop is a circle rather than being a rectangle. Also, it brings graphs into the question as well. The instructor goes through the cycle with the students as needed.

Implementing the clicker methodology does not require much effort from instructors using it. It generally requires no more than 20 minutes per lecture to incorporate 1 or 2 clicker question sequences into their lecture PowerPoint files, bring to the lecture hall computer, and test with the lecture hall clickers. As we will show in the next chapter, using our clicker methodology in the introductory physics courses at OSU has produced positive effects for our students.
CHAPTER 6

RESULTS

6.1 Introduction

We ascertained the effect of our clicker methodology on students by using surveys and conceptual pre/post tests. In this chapter, we present the results. First, we will present student surveys. Then, we will present two major findings from our conceptual test data. The first is that the timing of pre/post tests and the incentives offered for taking them has a marked effect on the test results [Ding, 2008]. The other is that the OSU Clicker Methodology effectively improves students’ conceptual understanding of introductory physics courses.

In Section 6.2, we will present the data obtained through survey forms that clicker students filled out at the end of the course. In Section 6.3, we will discuss the effects of testing conditions on conceptual test results and describe our final approach with the testing conditions. Then, we will discuss our data showing the dependence of measured learning gain on student access to the clicker material. In Section 6.4, we will present data that shows the effectiveness of the OSU Clicker Methodology.
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<thead>
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<th>Rating Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. I liked using clickers. (choose one)</td>
<td>-2 -1 0 +1 +2</td>
</tr>
<tr>
<td>2. Clickers helped me understand lectures better. (choose one)</td>
<td>-2 -1 0 +1 +2</td>
</tr>
<tr>
<td>3. Clickers made me feel involved in the course. (choose one)</td>
<td>-2 -1 0 +1 +2</td>
</tr>
<tr>
<td>4. Clickers helped me get instant feedback on what I knew and didn't know. (choose one)</td>
<td>-2 -1 0 +1 +2</td>
</tr>
<tr>
<td>5. Using clickers helped me think more deeply about course materials. (choose one)</td>
<td>-2 -1 0 +1 +2</td>
</tr>
<tr>
<td>6. I prefer questions that confirm what I already know. (choose one)</td>
<td>-2 -1 0 +1 +2</td>
</tr>
<tr>
<td>7. I prefer questions that require me to extend and make an intelligent guess. (choose one)</td>
<td>-2 -1 0 +1 +2</td>
</tr>
<tr>
<td>8. When it looks like most of the class has answered a particular clicker question correctly, how should we proceed? (Circle one)</td>
<td>Move on to the next point. Make a quick check that students answered the question for the right reasons. Go over the question in depth regardless of how many students got it right/wrong.</td>
</tr>
<tr>
<td>9. It bothers me if I get a question wrong, even though I may learn something. (choose one)</td>
<td>-2 -1 0 +1 +2</td>
</tr>
<tr>
<td>10. I would take another course that uses clickers. (choose one)</td>
<td>-2 -1 0 +1 +2</td>
</tr>
<tr>
<td>11. I would recommend using clickers in all future introductory physics courses. (choose one)</td>
<td>-2 -1 0 +1 +2</td>
</tr>
<tr>
<td>12. I will avoid classes using clickers in the future. (choose one)</td>
<td>-2 -1 0 +1 +2</td>
</tr>
<tr>
<td>13. Using clickers should be eliminated and the extra time used for more demonstrations. (choose one)</td>
<td>-2 -1 0 +1 +2</td>
</tr>
</tbody>
</table>

*Go to the back of this page to finish the questionnaire.*

Figure 6.1: Clicker Survey. The front side.
14. Using clickers should be eliminated and the extra time used for working more numerical problems.  
   (choose one)     -2  -1  0  +1  +2

15. I would like to receive credit for using clickers. That is, I believe that responses should be 
   graded in some fashion.  
   (choose one)     -2  -1  0  +1  +2

16. I would like to have only one question on any given topic rather than the series of 2 or 3 per 
   topic that were used this quarter.  
   (choose one)     -2  -1  0  +1  +2

17. During this quarter, how many times was your clicker either missing or didn’t work? Circle one 
   choice.  
   0 times  1 to 3 times  More than three times

18. What is your overall GPA, not including this quarter?

19. What are the most beneficial aspects you have received from using clickers? The least 
   beneficial?

Go to the back of this page to finish the questionnaire.

Figure 6.2: Clicker Survey. The back side.
6.2 Students’ View of the Clicker Methodology

As with any other instructional methodologies, we were interested in obtaining evaluations of our clicker methodology in two different dimensions. We were interested both in affective issues such as how students felt about the methodology and how much conceptual learning gain our material actually produced. Starting in Section 6.3, we will discuss the conceptual learning gain resulting from our clicker methodology. In this section, we will present our findings about how students feel about the methodology.

Clicker students were asked to fill out a clicker survey (front page: Figure 6.1; back page: Figure 6.2) in lecture during the last week of the course. In general, about 80% of enrolled students attended and approximately 90% of them filled out the survey form.

The survey had 17 rating questions and 2 open-ended question. Table 6.1 summarizes data collected from 2007 to 2008. Survey questions #1 – 7 and #9 – 16 ask students to rate each question using a Likert-like scale. The rating scale used was from -2 (strongly disagree) to +2 (strongly agree) with 0 being neutral. To minimize the possibility that high scores could be due to making only positive statements, we occasionally used paired questions such as “10. I would take another course that uses clickers” and “12. I will avoid classes using clickers in the future” which allowed us cross check. Survey question #10 was posed as a positive statement whereas question #12 was posed as a negative statement. A rating of +2 (strongly agree) for question #10 would be more or less equivalent to a rating of -2 (strongly disagree) for question #12. 

The average scores of survey questions #10 (1.45) and #12 (-1.44) were indicative of the
fact that student ratings were consistent independent of whether positive or negative statements were used.

In general, students were positive toward the clicker methodology. As Table 6.1 shows, students mostly felt that they were actively getting involved during the lectures (1.49 average rating) and that clicker methodology helped them to understand the material better (1.34 average rating). In the next chapter, we will show that students indeed did gain more conceptual understanding.

<table>
<thead>
<tr>
<th>Survey Question Number</th>
<th>E&amp;M 2007 Spring</th>
<th>Mechanics 2007 Fall</th>
<th>Waves 2008 Spring</th>
<th>Mechanics 2008 Fall</th>
<th>Combined Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.64</td>
<td>1.64</td>
<td>1.43</td>
<td>1.63</td>
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<td>2</td>
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<td>1.30</td>
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<td>1.47</td>
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</tr>
<tr>
<td>5</td>
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<td>0.95</td>
<td>0.89</td>
<td>1.00</td>
<td>0.98</td>
</tr>
<tr>
<td>6</td>
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</tr>
<tr>
<td>7</td>
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<td>0.89</td>
<td>0.97</td>
</tr>
<tr>
<td>8</td>
<td>2.2</td>
<td>2.09</td>
<td>2.11</td>
<td>2.23</td>
<td>2.16</td>
</tr>
<tr>
<td>9</td>
<td>-0.12</td>
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</tr>
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<td>10</td>
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<td>1.43</td>
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<td>-0.57</td>
<td>-0.68</td>
<td>-0.80</td>
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<tr>
<td>15</td>
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<td>0.70</td>
<td>0.63</td>
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</tr>
<tr>
<td>16</td>
<td>-1.16</td>
<td>-1.15</td>
<td>-0.88</td>
<td>-0.83</td>
<td>-1.01</td>
</tr>
<tr>
<td>17</td>
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<td>0.22</td>
<td>0.45</td>
<td>0.17</td>
<td>0.27</td>
</tr>
<tr>
<td>18</td>
<td>3.16</td>
<td>3.09</td>
<td>3.25</td>
<td>3.22</td>
<td>3.18</td>
</tr>
</tbody>
</table>

Table 6.1: The averages of student ratings of questions from the end-of-class clicker survey.
The 8th question (“When it looks like most of the class has answered a particular clicker question correctly, how should we proceed?”) uses a rating scale with +1 (“a. Move on to the next point”), +2 (“b. Make a quick check that students answered the question for the right reasons.”), and +3 (“c. Go over the question in depth regardless of how many students got it right/wrong.”). As shown in Table 6.1, the average for this question is 2.16 which indicates that students in general want to have a quick check that the students answered the question for the right reasons.

The 17th question asks how many times their clickers had problems and uses the scale 0 (0 times), +1 (1 to 3 times), and +2 (More than 3 times). Students reported that there were very few clicker problems. The problem was usually missing clickers, in which case the student was assigned a new clicker to use for the lecture.

The 18th question asks for student-reported GPA using +4 (for A) and 0 (for Fail). Students reported that their GPA was on average around 3.18, which is between a B and a B+.

Students were also free to write written comments on the end-of-class survey forms. About 77% of the survey collected had some written comments. Figure 6.3 shows the distribution of different types of student comments collected from 2007 Spring to 2008 Fall, which consisted of 433 positive aspects and 184 negatives aspects about the clicker methodology. 27 students wrote that there was no negative aspect. For every 1 negative aspect, there were about 2.4 positive aspects about the clicker methodology. In the following section, we will present some of the common comments and a short discussion.
6.2.1 Students’ Written Comments

The most common negative comment was that students wanted to see more worked out problems (about 25% of the 184 negative comments) and thought that answering clicker question sequences took time away (about 25% of the negative comments):

“Didn’t help me understand much more about problems.”

“More numerical calculations.”

“Too much class time taken.”

Figure 6.3: Clicker survey comments. Positive and negative student comments collected from 2007 Spring to 2008 Fall.
But students felt that answering clicker question sequences helped them in other aspects, such as helping them learn concepts (about 18% of the 433 positive comments) and providing instant feedback on their mastery of the concepts (about 20% of the positive comments):

“Actually learned something.”

“A great way to check what I know and what I didn’t.”

“Understanding of concepts.”

“Think more deeply.”

“Learning from mistakes.”

“See the big picture.”

“Prepared for quiz/test.”

However, any comments that made explicit reference to “getting quiz-like questions” were classified into the “MC Questions” category, shown in Figure 6.3, instead. These comments seemed to indicate that students found the clicker questions useful because the questions were similar to questions on tests that counted toward their course grade:

“They help in multiple choice test questions”

“Quiz”

“Getting quiz-like questions”

“Learning what types of questions... will be tested....”

In the following sections, we will see that our clicker methodology increased students’ conceptual learning but had very little effect on their performance on show-work problems on the course exams. Perhaps, if we could convince students to see the
crucial role conceptual understanding plays in expert-like problem solving skills, the negative comments mentioned above would be reduced.

About 25% of the positive comments indicated that they felt the clicker methodology results in active learning environment:

“Active involvement.”

“Instant feedback.”

“Interacting with other students.”

“More interested in lecture.”

“Ease of participation.”

“Learning using class voting.”

“Learning from mistakes.”

But some of the negative comments seem to indicate that they want more interactivity (about 10% of the negative comments):

“Correct answer was not told always.”

“Assuming everyone knows after the vote.”

As briefly mentioned earlier, it is important for the instructor to clearly indicate the correct answer and provide a summarizing explanation for the correct answer.

There were various types of student comments which were classified into the “Other (Positive)” and “Other (Negative)” types. Comments that were classified as “Other (Positive)” were:

“Extra credit”

“They help in multiple choice test questions”

“Fun”
“Makes me come to the lecture”

Examples of “Other (Negative)” comments are:

“It would be nice to have access to the questions afterward....”

“Coming to class a few minutes late and missing 1 or 2 clicker questions”

“I felt a lot rushed”

“Pressure”

These types of comments didn’t merit their own categories since the occurrence was small compared to the other categories shown in Figure 6.3. However, we did make our question sequences accessible to our clicker students starting Spring 2008, as discussed later in section 6.5.1.

In conclusion, as summarized in Table 6.1 and in Figure 6.3, students felt quite favorable toward our clicker methodology and believed that it helped them learn.

6.3 The Effects of Testing Conditions on Conceptual Survey Results

To measure the effectiveness of our clicker methodology in introductory physics courses, we conducted comparison studies at OSU using pre and post testing. Unfortunately, it is often difficult to control variables such as timing and incentives in delivering conceptual tests. Because course scheduling and instructor preferences, it sometimes is difficult to administer a pretest before instruction begins and a posttest after instruction ends. As a common practice, a pretest is often administered either at or near the beginning of a course and a posttest is given at or near the end of a course. Also, various incentives may be offered to students for taking these tests.
We analyzed four years of data collected from over 2100 OSU students who took both the pre and post test of the Conceptual Survey of Electricity and Magnetism (CSEM) [Maloney, 2001] under various timings and incentives. Our analysis indicated that the normalized gain can be changed as much as 30% just by changing the timing and incentives of pretests and posttests.

6.3.1 The Comparison Group (Fall 2003 – Fall 2005)

From Fall 2003 through Fall 2005, 9 different instructors taught the calculus-based introductory E&M course at OSU. During this period, 2 different textbooks [Halliday, 2005; Knight, 2004] and two different homework delivery systems were used. The materials covered in these courses were similar, lab and recitation sections were essentially the same, and the training of TAs also remained unchanged. The CSEM pretest was always given during the 2nd week of the quarter in lab sections. Students typically attended three or more lectures before completing the pretest. The CSEM posttest was always given in the last lab section, which was usually held during the second-to-last or the last week of the quarter. No incentives were given to students for taking either the pretest or the posttest. Because the test timings and the lack of incentives were the same for all these quarters, we combine these quarters together and refer to them as the “Comparison” group. This group of 1526 students is used as a baseline for comparison to courses with different timings and incentives. We have excluded one course offered during Fall 2005 because the instructor used clicker question
sequences in lecture. By doing so, we eliminated possible effects that use of these sequences might produce in CSEM results.

The posttest for the Comparison group was administered in the last lab section which was usually held during the second-to-last or the last week of the quarter with no incentives for taking the test. About 72% of the students took both the pretest and the posttest. The posttest average score for the Comparison group was 15.2 (48%).

We used normalized gain as a measure of learning gain. Normalized gain is expressed as:

\[
\text{Normalized Gain} = \frac{(\text{Posttest score})\% - (\text{Pretest score})\%}{100\% - (\text{Pretest score})\%}.
\]

Figure 6.4 shows the pretest averages, posttest averages, absolute gains, and normalized gains of the individual courses of the “Comparison” group during each quarter from Fall 2003 to Fall 2005. An ANOVA analysis shows that there is no significant difference across these quarters in the pretest scores \(F(8, 1526) = 0.84, p = 0.5678\), posttest scores \(F(8, 1526) = 0.43, p = 0.9052\), absolute gains \(F(8, 1526) = 0.91, p = 0.5097\), or normalized gain \(F(8, 1526) = 0.95, p = 0.4759\). In summary, analysis indicates that these quarters can be grouped together to form a comparison group.
6.3.2 Effects of Changes in Pretest Timing

The E&M courses offered in Winter 2006, Spring 2006, and Spring 2007 shared the same incentive as the Control group but the pretest was administered earlier than the Control group. In Winter 2006 and Spring 2007, the pretest was administered on the first day of class before any instruction (either in lecture or in recitation). We will refer to these courses as “No-Instruction” group. For the “No-Instruction” group, we combined the pretest scores from both the clicker and non-clicker sections, since none of these 563
students had any instruction. In Spring 2006, the pretest was administered to 100 non-clicker students and 54 clicker students after they already had attended one lecture.

A significant difference can be observed, as shown in Figure 6.5, between the Comparison group and the No-Instruction group. The Comparison group obtained significantly higher average pretest score (11.4 (35% correct out of 32 questions)) than the No-Instruction group (9.0 (28%)). It is clear that pretest scores can be significantly increased by a week of instruction.

Figure 6.5: Average total pretest scores of the Comparison group and the No-Instruction group.
An analysis of the data from Spring 2006 also indicates that sometimes even one lecture may produce noticeable effect in the pretest score. Whereas the first lecture of the non-clicker section of the course was used to address logistics and administrative issues and covered less course material, the instructor of the clicker section unknowingly discussed several CSEM questions in the first lecture. As a result, the average pretest score for the clicker section turned out to be 10.8, similar to the Comparison group. But the non-clicker section had an average pretest score of 9.0 which was comparable to the “No-Instruction” group.

Since even a single lecture can significantly affect pretest results, we believe it is important to have the pretest administered before any instruction.

<table>
<thead>
<tr>
<th>Timing</th>
<th>Incentives</th>
<th>Percentage of Students Taking Both the Pretest and the Posttest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Posttest Average ± Std. Err.</td>
<td>Timing</td>
<td>Incentives</td>
</tr>
<tr>
<td>Comparison group (N = 1535)</td>
<td>15.2 ± 0.1</td>
<td>Last lab session</td>
</tr>
<tr>
<td>Winter 2006 (N=175)</td>
<td>15.0 ± 0.5</td>
<td>Last lab session</td>
</tr>
<tr>
<td>Spring 2006 (N = 100)</td>
<td>17.6 ± 0.5</td>
<td>Last recitation session</td>
</tr>
<tr>
<td>Spring 2007 (N = 122)</td>
<td>19.9 ± 0.4</td>
<td>Final Exam</td>
</tr>
</tbody>
</table>

Table 6.2: Posttest results, conditions, and the percentage of pre-post match.
6.3.3 Effects of Changes in Posttest Timing and Incentives

Different posttest timings and incentives used for courses offered in Winter 2006, Spring 2006, and 2007 Spring are summarized in Table 6.2. For the posttest analysis, only data from the non-clicker sections were used to eliminate the possible effects caused by our clicker methodology.

6.3.3.1 Minimum Difference in Posttest Incentive

In Winter 2006, the posttest was offered with the same timing as for the Comparison group (in the last lab) but with an incentive. The incentive was a small amount of points that were added to the total points for the course, and was given to students just for taking the posttest regardless of how they performed.

Consequently, the percentage of students who took both the pretest and the posttest was about 90%, significantly higher than 72% for the Comparison group. However, the average posttest score was only 15.0, which was slightly but not significantly lower than the Comparison group average of 15.2. One possible explanation is that the incentive offered caused more students, including lesser-achieving students, to take the posttest. This in turn, may have resulted in a slightly lower average posttest score.
6.3.3.2 Medium Differences in Posttest Incentive and Timing

In Spring 2006, both the timing and the incentives differed from the Comparison group. The posttest was administered during the last recitation, which took place several days after the last lab. A different type of incentive was offered: the lowest quiz score could be replaced with the posttest score if the posttest score were greater than 90%.

The percentage of students taking both the pretest and the posttest dropped to about 65%. However, the average posttest score was significantly higher at 17.6 (55%).

One possible explanation is that this type of incentive may attract more students who are higher-achieving and better motivate. When we looked at the final course grades, we found that students who took both the pretest and the posttest received an average grade of 2.63 (A=4, B=3, C=2, D=1, Fail = 0), whereas those who missed at least one of these tests received an average grade of 1.86.
6.3.3.3 Maximum Differences in Posttest Incentive and Timing

In Spring 2007, the pretest occurred prior to any instruction. The posttest was incorporated into the final exam. The pretest was before instruction, while the posttest was after instruction and offered a maximal incentive.

The percentage of students who took both the pretest and the posttest rose to 95% and the average posttest score was 19.9 (62%) which was the highest among all of the

Figure 6.6: Average total pretest scores and the posttest scores of the Comparison group and the non-clicker courses offered in Winter 2006, Spring 2006, and Spring 2007.
quarters and was about 4.3 (13%) higher than the Comparison group. Figure 6.6 summarizes the pretest and the posttest averages for the all these courses.

6.3.4 Effects of Timing and Incentives on Normalized Gain

Figure 6.7 shows the normalized gains for the Comparison group and the three courses that used different timings and incentives. As can be seen from the figure, normalized gains of similar courses can be changed from 18.5% to 48.2% just by changing the timing and the incentives. 18% is the hallmark of an average course, while 48.2% would be the hallmark of an effective course.

Our results suggest that the CSEM pretest scores are sensitive to the timing of the test. Even a timing difference of as little as one lecture can significantly affect the pretest results. Also, the posttest timing and incentives can produce significant effects on the test results. The normalized gain, which depends on the pretest and posttest scores, can vary from 18.5% to 48.2%. This variation makes it harder to compare the effects of instructional methodologies, since it may mask smaller yet real changes produced by instructional methodologies.
So, we administered our pre and post tests with the maximum timing and incentives by giving the pretest before instruction and the posttest on the final exam. In the following section, we will discuss this procedure in more detail.
6.4 The Effect of Limited Accessibility

Based on our findings with the timing and incentives and their effects on CSEM scores, we conducted our evaluation of the OSU Clicker Methodology by giving the pretest before any instruction and the posttest on the final exam. However, we discovered that administering the pre and post tests this way resulted in measurements that indicated no significant increase for the clicker section over the non-clicker section.

Students did not know beforehand which classes used clickers. Students enrolled in the clicker section found out about clickers on the first day of lecture. Students enrolled in the non-clicker section were not told of clickers.

Initially, we limited student access to the clicker question sequences. Clicker question sequences were shown to clicker students only in lectures.

However, the gain for the clicker section came back when we allowed only clicker section students access to clicker question sequences. We will discuss both cases in the following sections.

6.4.1 Limited Access: E&M in Spring 2007

In Spring 2007, we conducted our comparison study between Electricity and Magnetism (E&M) lecture sections, which were offered at 8:30am and 9:30am. The 8:30am section was taught by one of the researchers and used the OSU Clicker Methodology. The 9:30am section was taught by a physics professor in a traditional
method without using the methodology. Both sections started with comparable student size, 124 students in the clicker section and 132 students in the non-clicker section.

The CSEM was given as the pretest before any instruction in the first lecture of both the clicker class and the non-clicker class. There were 114 students in the clicker section and 136 students in the non-clicker section took the pretest. We compared results on the pretest to see if there was a big difference between the student populations in the two sections.

Figure 6.8: The pretest score distributions of matched students in the clicker section and the non-clicker section of the 2007 Spring introductory E&M course at OSU.
To compare the distributions of pretest scores for both sections, shown in Figure 6.8, the Two-Sample two-tailed t Test [Devore, 2000] with a confidence level of 95% was used. Since the t Test is robust against moderate violations of normality [Boneau, 1960], we used it to compare the distributions of scores for all our comparisons. Large deviation from normality was checked by inspecting the histograms and using skew and kurtosis values. We also used Shapior-Wilk’s test [Shapiro, 1965] to inspect normality, and no large deviation was detected. Even though the average number of questions that were answered correctly was 8.2 (25.6%) for the clicker section (106 matched students) and 8.8 (27.4%) for the non-clicker section (122 matched students), this was not a statistically significant difference (t = 1.1953, p = 0.2332). Figure 6.9 shows how students performed on each question of the pretest.

The posttest was given as a part of the final exam. The final exam contained 36 multiple-choice questions, which were worth half of the total points on the final exam. The first 32 multiple-choice questions on the final exam were the 32 CSEM questions. The remaining 4 questions, shown in Appendix D, were made up of 1 magnetic force question (#33) and 3 circuit questions (#34 - #36). Question #34 and #36 were modified versions of questions #29 and #21 of the DIRECT [Engelhardt, 2004], respectively. These multiple-choice questions covered conceptual material taught in the course, but were different from the clicker questions.

Because we were interested in measuring student learning gains by calculating the score difference between pretests and posttests, we will select and examine only “matched” students who took both the pretest and the posttest.
Figure 6.9: The fraction of 2007 Spring introductory E&M OSU students (matched) in the clicker section and the non-clicker section answering each pretest question correctly.

There were 106 matched students in the clicker section and 122 matched students in the non-clicker section. The Two-Sample two-tailed t Test with a confidence level of 95% was used to compare the distributions of posttest scores for both sections, which are shown in Figure 6.10.

The average number of questions that were answered correctly was 20.5 (64.1%) for the clicker section (106 matched students) and 20.0 (62.4%) for the non-clicker section (122 matched students). Figure 6.11 shows how students performed on each question of the posttest. There was no significant difference ($t = 0.7920, p = 0.4292$).
The normalized gain was 51.6% for the clicker section and 48.4% for the non-clicker section, which was not statistically significant ($t = 1.3785$, $p = 0.1710$; $d = 0.1537$) [Cohen, 1969]. This was surprising, since all previous E&M clicker sections had showed significantly higher average posttest scores than the non-clicker sections [Li, 2007]. Even though our previously conducted studies didn’t use maximal timing and incentives, we were able to arrive at this conclusion by comparing posttests for clicker and non-clicker lecture sections offered during the same quarter. At this time, we were not clear as to what was causing the disappearance of the clicker section’s advantage over
the non-clicker section. We conducted a similar study with the Mechanics course in the following quarter.

Figure 6.11: The fraction of 2007 Spring introductory E&M OSU students (matched) in the clicker section and the non-clicker section answering each posttest question correctly.

6.4.2 Limited Access: Mechanics in Fall 2007

During the Fall quarter of 2007, we conducted our comparison study with both of the Mechanics courses which were offered at 2:30pm and 3:30pm. The 2:30pm section was taught by a physics professor in a traditional method without using the methodology.
The 3:30pm section was taught by one of the researchers and used the OSU Clicker Methodology. Both sections started with comparable student size of about 215 students which was the maximum enrollment size for the course.

The pretest contained 34 multiple-choice questions and was given in the first recitation meeting, which was one day after the first lecture. It did not count toward the course grade. The first 26 questions on the pretest were the MBT [Hestenes, 1992]. The remaining 8 questions, shown in Appendix E, were not used on the posttest. However, some of these questions were used as a pretest during the Fall quarter of 2008 and will be used to compare the Mechanics student populations in our study, Fall 2007 and Fall 2008 courses. Pretest questions #27 and #28 are modified versions of the FMCE [Thornton, 1998] questions #30 and #32. Pretest question #29 is from Ding’s energy assessment [Ding, 2007]. Pretest questions #30 and #31 are questions #4 and #5 of the Energy and Momentum Conceptual Survey [Singh, 2003]. Pretest questions #33 and #34 are about rotation, and were constructed by us.

There were 198 students in the clicker section and 208 students in the non-clicker section who took the pretest. We compared the results on the pretest to see if there was a difference between student populations of clicker and non-clicker lecture sections.

To compare the distributions of MBT pretest scores for both sections, shown in Figure 6.12, the Two-Sample two-tailed t Test with a confidence level of 95% was used. The average number of the MBT questions that were answered correctly was 10.10 (38.9%) for the clicker section (184 matched students) and 10.85 (41.7%) for the non-clicker section (171 matched students). This was a statistically significant difference.
between the clicker section and the non-clicker section (t = 2.0876, p = 0.0375). Figure 6.13 shows how students performed on each question of the pretest.

Figure 6.12: The MBT pretest score distributions of matched students in the clicker section and the non-clicker section of the 2007 Fall introductory Mechanics course at OSU.

Figure 6.12: The MBT pretest score distributions of matched students in the clicker section and the non-clicker section of the 2007 Fall introductory Mechanics course at OSU.
Figure 6.13: The fraction of 2007 Fall introductory Mechanics OSU students (matched) in the clicker section and the non-clicker section answering each MBT pretest question correctly.
The same steps were taken to compare distributions of the 8 additional questions of the pretest for both sections, shown in Figure 6.14. There was no statistically significant difference between the two sections. The average number of questions that were answered correctly for the 8 questions was 1.55 (5.96%) for the clicker section and 1.77 (6.82%) for the non-clicker section. There was no significant difference (t = 1.5153, p = 0.1306). Figure 6.15 shows how matched students performed on each of the 8 questions.

Figure 6.14: Pretest scores for the 8 non-MBT questions (questions #27 - #34).

Distributions of matched students in the clicker section and the non-clicker section of the 2007 Fall introductory Mechanics course at OSU.
Figure 6.15: The fraction of 2007 Fall introductory Mechanics OSU students (matched) in the clicker section and the non-clicker section answering each of pretest questions #27 - #34 correctly.

The posttest was given as a part of the final exam. The final exam contained 26 multiple-choice questions which were worth 39% of the total points on the final exam. The multiple-choice questions on the final exam were the 26 questions from the MBT.

There were 195 students in the clicker section and 177 students in the non-clicker section who took the posttest. There were 184 matched students in the clicker section and 171 matched students in the non-clicker section. The Two-Sample two-tailed t Test with a confidence level of 95% was used to compare the distributions of posttest scores for both sections, shown in Figure 6.16.
Figure 6.16: The posttest score distributions of matched students in the clicker section and the non-clicker section of the 2007 Fall introductory Mechanics course at OSU.

The difference between the average numbers of questions that were answered correctly was not statistically significant ($t = 0.4250$, $p = 0.6711$). The average number was 15.73 (60.5%) for the clicker section (184 matched students) and 15.90 (61.2%) for the non-clicker section (171 matched students). Figure 6.17 shows how students performed on each question of the posttest.
There was no statistically significant difference in the normalized gain between the clicker section and the non-clicker section ($t = 0.5942, p = 0.5536; d = 0.1006$). The normalized gain was 35.0% for the clicker section and 33.0% for the non-clicker section.

This seemed to indicate that using maximum timing and incentives somehow wipes out any additional conceptual learning gain produced by the clicker methodology. Worth noting is the fact that students review for final exams, and it was not possible to

Figure 6.17: The fraction of 2007 Fall introductory Mechanics OSU students (matched) in the clicker section and the non-clicker section answering each posttest question correctly.

This seemed to indicate that using maximum timing and incentives somehow wipes out any additional conceptual learning gain produced by the clicker methodology. Worth noting is the fact that students review for final exams, and it was not possible to
review clicker questions. At this time there were two things that we were able to experiment with. First, we were able to see if clicker students were able to retain their learning better than the non-clicker students. This will be discussed next in Section 6.4.2.1. The other possibility was that to give clicker students full access to the clicker material which did the job. This will be discussed in Section 6.5.

6.4.2.1 Limited Access: Retention of Conceptual Learning in Mechanics

In the following quarter, we administered the MBT, as a time-delayed posttest, again to measure if there was any effect of the OSU Clicker Methodology on students’ retention of the course material. Most of the students who took the Mechanics course in Fall 2007 continued to take the next sequence in the introductory physics series. So, the MBT was given to students in both sections of the E&M course in Winter 2008.

The MBT is exactly the pretest for the Fall 2007 Mechanics course and was administered on the first day of the quarter, which came before the first lecture, in recitation sessions. Because we are interested in measuring what happens to students scores on the MBT after some time after the course, we only analyzed tests of students who took the pretest and the posttest in the Fall 2007 Mechanics course and another posttest in the Winter 2008 E&M course. There were 103 such students who went through the clicker section of the Fall 2007 Mechanics course and 124 such students who went through the non-clicker section. We will use the term “delay-matched” to refer to such students.
Using a confidence level of 95%, the Two-Sample two-tailed t indicates that there is no statistically significant difference ($t = 1.3533$, $p = 0.1773$) between the distributions of the pretest (taken during the first discussion session of the Fall 2007 Mechanics course) scores of delay-matched students who went through the clicker section, 10.2 (39.2%), and students who went through the non-clicker section, 10.7 (41.2%), shown in Figure 6.18. Figure 6.19 shows how delay-matched students performed on each question of the pretest.

Figure 6.18: The pretest score distributions of delay-matched students in the clicker section and the non-clicker section of the 2007 Fall introductory Mechanics course at OSU.
Figure 6.19: The fraction of 2007 Fall introductory Mechanics OSU students (delay-matched) in the clicker section and the non-clicker section answering each pretest question correctly.

The time-delayed posttest (taken at the beginning of the Winter quarter of 2008) scores of delay-matched students were analyzed using a confidence level of 95%, the Two-Sample two-tailed t Test. The average of delay-matched students of the clicker section was 16.0 (61.5%) and of the non-clicker section was 16.1 (62.0%). There was no statistically significant difference ($t = 0.3332, p = 0.7393$) between them and Figure 6.20 shows the distributions for both sections.
Figure 6.20: The time-delayed posttest score distributions of delay-matched students in the clicker section and the non-clicker section of the 2007 Fall introductory Mechanics course at OSU.

Figure 6.21 displays how delay-matched students performed on each question of the time-delayed posttest (taken in the Winter quarter of 2008).

There was no statistically significant difference ($t = 0.2453$, $p = 0.8067$; $d = 0.0475$) in the normalized gain between the delay-matched students of the clicker section and the non-clicker section. The normalized gain was 35.1% for the clicker section and 34.1% for the non-clicker section.
Figure 6.21: The fraction of 2007 Fall introductory Mechanics OSU students (delay-matched) in the clicker section and the non-clicker section answering each time-delayed posttest (taken in the Winter quarter of 2008) question correctly.

The final grade distributions of the delay-matched students are shown in Figure 6.22. Using a confidence level of 95%, the Two-Sample two-tailed t Test indicates that there is no statistically significant difference between the final grade distributions of the clicker section (average grade of 2.8, which is approximately a B-) and the non-clicker section (average grade of 2.6, which is approximately a B-). Therefore, the delay-
matched student populations of the clicker and non-clicker sections are not significantly different.

Figure 6.22: The final grade distributions of 2007 Fall introductory Mechanics OSU students (delay-matched) in the clicker section and the non-clicker section.

Figure 6.23 summarizes the average scores on the pretest, posttest, and the time-delayed posttest. It appears that if they are not permitted to review clicker material, clicker students do not significantly outperform non-clicker students on conceptual tests. Also, the retention does not change significantly when tested again in 4 weeks.
In the following quarters, we put the clicker question sequences on a password-protected course web site to allow clicker students full access to them but minimize access for the non-clicker students.

Figure 6.23: Average scores on pretest, posttest, and time-delayed posttest.

6.5 Full Access to Clicker Material

By this time, we hypothesized that the posttest being put on the final exam gives the maximum incentives to students to do well on the posttest. Therefore, students in
both the clicker section and the non-clicker section will prepare for the test and any advantage the clicker methodology provided is masked by students’ preparation for the final exam. We also hypothesized that students in the clicker sections should have full access to the clicker question sequences. In the following two quarters, we tested this hypothesis and we observed significantly higher normalized gain for the clicker sections.


During Spring 2008, we conducted a comparison study with both of the Waves, Optics & Modern Physics courses which were offered at 2:30pm and 3:30pm. The 2:30pm section was taught by a physics professor in a traditional method without using the methodology. The 3:30pm section was taught by one of the researchers and used the OSU Clicker Methodology. Both sections had the enrollment capacity of 182 students. The clicker section started with 177 students and the non-clicker section started with 161 students. All clicker question sequences were placed on a secure web site and only the clicker students had direct access. Solutions to the questions were discussed in lectures only. No solutions were given on the web site.

The pretest contained 19 multiple-choice questions, of which only 17 questions were used in the posttest, and was given in the first recitation meeting, which was one day after a first lecture occupied mostly with administrative duties. It did not count toward the course grade. Appendix F shows the pretest (questions #13 and #19 were dropped for posttest).
There were 163 students in the clicker section and 147 students in the non-clicker section who took the pretest. There were 156 matched students in the clicker section and 140 matched students in the non-clicker section.

Figure 6.24: The pretest score distributions of matched students in the clicker section and the non-clicker section of the 2008 Spring introductory Waves, Optics, & Modern Physics course at OSU.

To compare the distributions of pretest scores for both sections, shown in Figure 6.24, the Two-Sample two-tailed t Test with a confidence level of 95% was used. The average number of the questions that were answered correctly was 5.2 (19.9%) for the
clicker section and 5.2 (19.9%) for the non-clicker section. There was no statistically significant difference (t = 0.0368, p = 0.9707) between the clicker section and the non-clicker section. Figure 6.25 shows how students performed on each question of the pretest.

Figure 6.25: The fraction of 2008 Spring introductory Waves, Optics & Modern Physics OSU students (matched) in the clicker section and the non-clicker section answering each pretest question correctly.
The posttest was given as a part of the final exam, which was all multiple-choice questions. The first 17 questions were the posttest questions and were worth 68 points out of 185 points.

![Bar chart showing fraction of students vs. total number of questions answered correctly](image)

Figure 6.26: The posttest score distributions of matched students in the clicker section and the non-clicker section of the 2008 Spring introductory Waves, Optics, & Modern Physics course at OSU.

170 students in the clicker section and 148 students in the non-clicker section took the posttest. There were 156 matched students in the clicker section and 140 matched students in the non-clicker section. Using a confidence level of 95%, the Two-Sample
two-tailed t Test indicates that there is a statistically significant difference ($t = 5.7825, p < 0.0001$) between the distributions of the posttest scores for matched students of both sections, shown in Figure 6.26. The average number of questions that were answered correctly was 12.2 (46.8%) for the clicker section, which exceeds the average for the non-clicker section 10.3 (39.4%). Figure 6.27 displays how students performed on each question on the posttest.

![Graph showing the fraction of students answering correctly for each question on the posttest for both clicker and non-clicker sections.]  

Figure 6.27: The fraction of 2008 Spring introductory Waves, Optics & Modern Physics OSU students (matched) in the clicker section and the non-clicker section answering each posttest question correctly.
The normalized gain of 58.6% for the clicker section exceeded 41.3% for the non-clicker section, and the difference was statistically significant at the 95% confidence level (t = 5.9548, p < 0.0001; d = 0.6487).

Figure 6.28 shows the average normalized gain vs. final course grade for both the clicker section and the non-clicker section. The fitted lines have similar slopes, which suggests that the clicker methodology helps all students equally, independent of their final course grades.

![Figure 6.28: Average normalized gain vs. final course grade for 2008 Spring introductory Waves, Optics, & Modern Physics.](image)
The results indicated that giving clicker students full access to the clicker question sequences produced significantly higher conceptual learning. Based on these positive results, we continued this study with Mechanics.

### 6.5.2 Full Access: Mechanics in Fall 2008

During the Fall quarter of 2008, we conducted another comparison study with Mechanics courses which were offered at 2:30pm and 3:30pm. The 2:30pm section was taught by one of the researchers and used the OSU Clicker Methodology. The 3:30pm section was taught by a physics professor in a traditional method without using the methodology. Both sections started with 215 students enrolled, which was the maximum enrollment size for the course. All clicker question sequences were placed on a secure web site and only the clicker students had direct access. Solutions were discussed in lectures only. No solutions were given on the web site.

The pretest, shown in Appendix G, contained 18 multiple-choice questions and was given in the first recitation meeting, which was one day after the first lecture. It did not count toward the course grade.

There were 199 students in the clicker section and 216 students in the non-clicker section who took the pretest. At the time of the pretest, anyone who came to the discussion section took the test regardless of their enrollment status. However, this does not present any problem to our analysis because we only look at the matched students. There were 185 matched students in the clicker section and 198 in the non-clicker section.
Using a confidence level of 95%, the Two-Sample two-tailed t Test indicates that there is no statistically significant difference ($t = 0.0816$, $p = 0.9350$) between the distributions of the pretest scores for both sessions, shown in Figure 6.29. The average pretest score of the clicker section, 5.0 (19.4%) questions correct, and the non-clicker section, 5.1 (19.5%). Figure 6.30 shows how students performed on each question of the pretest.
As mentioned previously, the pretest for Fall 2007 Mechanics course and the pretest for Fall 2008 Mechanics course share 6 common questions and these common questions will be used to compare the student populations of both courses. These questions are questions #27 - #32 of the pretest for Fall 2007 Mechanics course which is shown in Appendix E.
Figure 6.31: The score (on the 6 common questions on the pretest) distributions of matched students in the clicker section and the non-clicker section of the 2007 Fall and 2008 Fall introductory Mechanics course at OSU.

Figure 6.31 shows the distributions of scores on the 6 common questions for both sections of the Fall 2007 and 2008 Mechanics courses. Figure 6.32 shows how students performed on each of the 6 common questions. The average score on these questions is 1.2 (4.5%) for the 2007 clicker section, 1.2 (4.7%) for the 2007 non-clicker section, 1.5 (5.8%) for the 2008 clicker section, and 1.4 (5.3%) for the 2008 non-clicker section. Within the same quarter, the clicker section and the non-clicker section did not have statistically significant difference in the average scores. However, using a confidence
level of 95%, the average score of the Fall 2008 clicker section exceeds the both sections of Fall 2007 by about 0.3 points.

Figure 6.32: The fraction of 2007 Fall and 2008 Fall introductory Mechanics OSU students (matched) in the clicker section and the non-clicker section answering each of the 6 common questions on the pretest correctly.

The posttest was given as a part of the final exam. The final exam contained the same 18 multiple-choice questions as the ones used for the pretest, but some changes were made because the clicker section and the non-clicker section were taking the final exam at different times. The answers for each question were shuffled and the ordering
had to be changed to fit the pagination requirement for the final exam. The first 15
questions remained the same, but question #18 on the pretest became question #16 on the
posttest, questions #16 and #17 on the pretest became questions #17 and #18 on the
posttest, respectively. The multiple-choice questions were worth 81 points out of 200
points for the whole exam.

There were 199 students in the clicker section and 206 students in the non-clicker
section who took the final exam. Using a confidence level of 95%, the Two-Sample two-
tailed t Test indicates that there is a statistically significant difference ($t = 4.2628$, $p <
0.0001$) between the distributions of the posttest scores for matched students of both
sections, shown in Figure 6.33. The average number of questions that were answered
correctly was 11.1 (42.7%) for the clicker section and 9.9 (40.0%) for the non-clicker
section. The average number for the clicker section exceeds that of the non-clicker
section by about 1.2 questions, with a confidence level of 95%. The question order used
for the posttest is used to display how students performed on each question on the
posttest in Figure 6.34.

The normalized gain was 28.5% for the clicker section and 22.7% for the non-
clicker section. The difference was significant and sizable ($t = 4.5165$, $p < 0.0001$; $d =
0.4356$). The normalized gain for the clicker section exceeds that of the non-clicker
section by about 5.8%, with a confidence level of 95%.

Figure 6.35 compares the average normalized gain vs. final course grade for both
the clicker section and the non-clicker section. The fitted lines have similar slopes, which
suggests that the clicker methodology helps all students equally, independent of their
final course grades.
Figure 6.33: The posttest score distributions of matched students in the clicker section and the non-clicker section of the 2008 Fall introductory Mechanics course at OSU.
Figure 6.34: The fraction of 2008 Fall introductory Mechanics OSU students (matched) in the clicker section and the non-clicker section answering each posttest question correctly.
6.6 Discussion

The timing of the pretest and the posttest can introduce large uncertainties in the measurement of the normalized gain. Therefore, we believe it is best to maximize timing and incentives. This can be done by administering the pretest before any instruction and posttest after instruction. By giving the posttest on the final exam, students have maximal incentive to do their very best. We have administered the pretest and the
posttest in this way for the studies summarized in Table 6.3. We conducted 4 studies (2 in Mechanics, 1 in E&M, and 1 in Waves, Optics & Modern Physics) to evaluate the effectiveness of our clicker methodology. In two of these studies, we allowed the clicker students to see the clicker question sequences only in lectures. We wanted to prevent the non-clicker sections from being able to access them. So, we did not make them accessible to students. In the other two studies, we put the clicker question sequences online so the students enrolled in the clicker section have access at any time after they were used in lecture. In courses where students had access, the clicker sections had significantly higher normalized gain than the non-clicker sections. For example, the Mechanics course in Fall 2008 (28.5% vs. 22.7%) and the Waves, Optics & Modern Physics in Spring 2008 (58.6% vs. 41.3%) had statistically higher normalized gain than the non-clicker sections. Also, the clicker methodology helped every student equally, independent of their final course grades.

But, if clicker question sequences were shown once and only once in lecture, the measured effectiveness of the methodology became statistically non-significant (for example, 35% vs. 33.0% for Mechanics in Fall 2007 and 51.6% vs. 48.4% for E&M in Spring 2007). This data seems to indicate that without having further access to the question sequences, students’ conceptual understanding and retention of the material were not significantly affected by the clicker methodology. As a result, a new methodology was established. Clicker question sequences used in any given lecture are placed on a secure web site following that lecture.
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<th>Course</th>
<th>Quarter</th>
<th>Section</th>
<th># of Students (Pretest)</th>
<th># of Students (Posttest)</th>
<th># of Matched Students</th>
<th>Average Pretest Score (Matched Students)</th>
<th>Average Posttest Score (Matched Students)</th>
<th>Normalized Gain</th>
<th>Significant Difference (with a 95% confidence level)</th>
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<td>2007 Fall</td>
<td>Clicker</td>
<td>198</td>
<td>195</td>
<td>184</td>
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<td>15.73 (60.5%)</td>
<td>35.0%</td>
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<td>208</td>
<td>177</td>
<td>171</td>
<td>10.85 (41.7%)</td>
<td>15.90 (61.2%)</td>
<td>33.0%</td>
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<tr>
<td>P131</td>
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<td>Clicker</td>
<td>199</td>
<td>199</td>
<td>185</td>
<td>5.04 (19.4%)</td>
<td>11.10 (42.7%)</td>
<td>28.5%</td>
<td>Yes</td>
</tr>
<tr>
<td>P131</td>
<td>2008 Fall</td>
<td>Non-Clicker</td>
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<td>206</td>
<td>198</td>
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<td>9.87 (40.0%)</td>
<td>22.7%</td>
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<td>114</td>
<td>120</td>
<td>106</td>
<td>8.21 (25.6%)</td>
<td>20.50 (64.1%)</td>
<td>51.6%</td>
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</tr>
<tr>
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<td>122</td>
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<td>Clicker</td>
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<td>148</td>
<td>140</td>
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<td>10.25 (39.4%)</td>
<td>41.2%</td>
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</tbody>
</table>

Table 6.3: Pretest and posttest scores of the clicker sections and non-clicker sections.
CHAPTER 7

SUMMARY

As part of ongoing research by the Physics Education Research Group at the Ohio State University (OSU), this dissertation project has been conducted to develop and evaluate the OSU Clicker Methodology. Previous chapters in the dissertation motivated this research, reviewed the other research findings relevant to our research, described the creation and validation of our clicker question sequence, suggested ways of implementing the clicker methodology in lecture, and analyzed the effectiveness of the methodology. Our results will be summarized in this chapter.

We are nearing the completion of our clicker research. We have created and validated 167 research-based clicker question sequences for entire introductory physics courses. Each question in a sequence involves the same concept but has different contexts. Answer choices for the questions in a sequence are designed to address students preexisting knowledge. Each sequence provides multiple formative assessments and promotes active discussions. The combination of these is in line with the contemporary view that stresses the active construction, preexisting knowledge, and context dependence of learning.
We found that question validation requires inputs from both the physics experts and introductory physics students. Experts determine whether the clicker question sequences are technically correct, relevant, and cover major topics taught in introductory physics courses. Introductory physics students identify existing issues, or lack of, that would cause students to misinterpret the questions.

We also found that students’ affective domains were positively affected by the clicker methodology. Students enjoyed the clicker methodology and believed that it helped them learn better. Analysis of the conceptual tests indicated that students did indeed learn concepts better when the clicker methodology was used. Students learning with the clicker methodology obtained higher normalized gain ranging from 6% to 17%.

We also discovered that students needed to have full access to clicker question sequences to reap the maximum benefit. If the students saw the sequences only once in lecture but didn’t have a chance to see them again, other learning efforts such as studying for the final exam may overwhelm and make it difficult to measure any learning gain resulting from the methodology.

In conclusion, we believe we now have a comprehensive instructional methodology students enjoy that produces higher conceptual learning gain. Students appreciate the fact that the clicker methodology brings active learning to large lecture classroom. Students are given multiple formative assessments with immediate feedback. Students participate in class-wide discussions with their peers and/or the instructor.

As we approach the completion of the project, we are getting ready for the final step, which is the dissemination of our clicker research to others. We plan to do this by distributing all the research-based clicker question sequences at various workshops and
presentations. We will start the dissemination by offering a workshop and a poster session at the 2009 American Association of Physics Teachers national meeting in Ann Arbor, Michigan. The complete sequences will also be made available online at www.votingmachine.net and www.physics.ohio-state.edu/~physedu/clicker.
APPENDIX A

CLICKER QUESTION SEQUENCES

FOR

MECHANICS
Figure A.1: Mechanics Clicker Question Sequence A1 – A warm-up question to get students familiarized with clicker usage.

Matt’s mother has four lovely baby sons after four years of happy marriage. Their names are Michael I, Michael II, Michael III, and… Wait! what is her fourth son’s name?

1. Michael IV  
2. Mark  
3. Max  
4. Marshall  
5. None of the above
The speed of light is $3 \times 10^8$ m/s. How many kilometers does light travel in one second?

1. $3 \times 10^3$
2. $3 \times 10^5$
3. $3 \times 10^8$
4. $3 \times 10^{13}$
5. None of the above

In science, “light year” is used to measure how far light travels in a year. According to this definition, which of the following units is correct for “light year”?

1. kg (kilogram)
2. s (second)
3. m (meter)
4. m/s (meter per second)
5. kg·m/s (kilogram meter per second)

According to the definition of “light year” (the distance traveled by light in a year), we know: 1 light year =

1. $3 \times 10^8$ m
2. $3 \times 10^8$ 365 m
3. $3 \times 10^8$ 365 24 m
4. $3 \times 10^8$ 365 24 60 m
5. $3 \times 10^8 \times 365 \times 24 \times 60 \times 60$ m
A ball is launched vertically upward from ground level with an initial velocity of 30 m/s. How much time does it take before it lands on the ground? Use $|g|=10 \text{ m/s}^2$.

1. 1 s
2. 2 s
3. 3 s
4. 4 s
5. 6 s
6. None of the above.

A ball is launched vertically upward from ground level with an initial velocity of 30 m/s. What maximum altitude does it reach above the ground? Use $|g|=10 \text{ m/s}^2$.

1. 1 m
2. 2 m
3. 3 m
4. 4 m
5. 6 m
6. None of the above.

Figure A.3: Mechanics Clicker Question Sequence A3
You throw a ball vertically upward. Which statement best describes the direction and magnitude of the ball’s acceleration while the ball is still moving up?

1. Upward, constant magnitude
2. Upward, increasing magnitude
3. Upward, decreasing magnitude
4. Downward, constant magnitude
5. Downward, increasing magnitude
6. Downward, decreasing magnitude
7. Zero acceleration

You throw a ball vertically upward. Which statement best describes the direction and magnitude of the ball’s velocity while the ball is still moving up?

1. Upward, constant magnitude
2. Upward, increasing magnitude
3. Upward, decreasing magnitude
4. Downward, constant magnitude
5. Downward, increasing magnitude
6. Downward, decreasing magnitude
7. Zero velocity

You throw a ball vertically upward. The ball moves up, reaches its highest point, and finally falls down. Which of the following graphs best represents the ball’s acceleration and velocity vs. time during the process?

Figure A.4: Mechanics Clicker Question Sequence A4
A car starting from rest speeds up to 30 m/s with a constant acceleration over a time of 10 seconds. Then, it travels at 30 m/s for 10 seconds, and finally brakes to a stop in 20 seconds with a constant deceleration. Which of the following graphs represents its graph of speed versus time?

1. A
2. B
3. C
4. D

A car starting from rest speeds up to 30 m/s with a constant acceleration over a time of 10 seconds. Then, it travels at 30 m/s for 10 seconds, and finally brakes to a stop in 20 seconds with a constant deceleration. How far does it travel in the 40 second time period?

1. 100 m
2. 200 m
3. 400 m
4. 800 m
5. None of the above.

Figure A.5: Mechanics Clicker Question Sequence A5
A Cat spots a flowerpot that sails up past an open window. The pot, which passed by very close to the window, is in view for 0.25 s while going up, and the top-to-bottom height of the window is 2.00 m. How high above the top of the window does the flowerpot go? Can you solve this by plugging a single time into one of the furnished equations?

Can you solve this by plugging a single time into one of the furnished equations?

1. Yes
2. No
3. Can’t decide.

A Cat spots a flowerpot that sails up past an open window. The pot, which passed by very close to the window, is in view for 0.25 s while going up, and the top-to-bottom height of the window is 2.00 m. Intermediate step: What is the pot's upward velocity at the bottom of the window?

\[ g = -9.8 \text{ m/s}^2 \]

1. 8.000 m/s
2. 8.575 m/s
3. 9.225 m/s
4. 9.800 m/s
5. None of the above.

A Cat spots a flowerpot that sails first up past an open window. The pot, which passed by very close to the window, is in view for 0.25 s while going up, and the top-to-bottom height of the window is 2.00 m. How high above the top of the window does the flowerpot go?

\[ g = -9.8 \text{ m/s}^2 \]

1. 4.68 m
2. 4.34 m
3. 2.34 m
4. It doesn’t reach the top of the window
5. None of the above.

Figure A.6: Mechanics Clicker Question Sequence A6
Driving a car at in the positive x direction at 60 MPH, Mary tests her brakes by coming to a complete stop in 4 seconds. Then she resumes speed, taking 8 seconds to return to 60 MPH. A motion diagram is created by illuminating her car with a strobe at 2 second intervals. Which of the following best represents the correct diagram? Mary’s car is represented by a dot.

A  
B  
C  
D

Driving a car in the positive x direction at 60 MPH, Mary tests her brakes by coming to a complete stop at a constant rate of deceleration in 4 seconds. Then she resumes speed, taking 8 seconds to return to 60 MPH. Which of the following graphs best represents her velocity?

Driving a car in the positive x direction at 60 MPH, Mary tests her brakes by coming to a complete stop in 4 seconds. Then she resumes speed, taking 8 seconds to return to 60 MPH. Which of the following best represents her acceleration?

A  
B  
C  
D

Figure A.7: Mechanics Clicker Question Sequence A7
Driving a car in the positive x direction at 60 MPH (equivalent to 88 ft/sec), Mary tests her brakes by coming to a complete stop in 4 seconds. Then she resumes speed, taking 8 seconds to return to 60 MPH. What is the value for her acceleration while stopping?

1. 88 ft/sec^2
2. 44 ft/sec^2
3. 22 ft/sec^2
4. -22 ft/sec^2
5. -44 ft/sec^2
6. -88 ft/sec^2
(a) Which of the graphs of velocity versus time could correspond to the graph of acceleration versus time shown on the right?

(b) Which of the graphs of distance versus time corresponds to the graph of acceleration versus time shown on the right?

(c) Which of the graphs of acceleration versus time corresponds to the graph of distance versus time shown on the right?

Figure A8: Mechanics Clicker Question Sequence A8
Mr. Ant, standing in an elevator, moves up 40 m with the elevator. He then gets out of the elevator and walks straight for 3 minutes at a speed 10 meters/minute. What is the magnitude of Mr. Ant’s net displacement?

1. 0 m  
2. 30 m  
3. 40 m  
4. 50 m  
5. 70 m  
6. Not enough information given

Mr. Q starts to walk along the dotted line painted on the moving walkway. The width of the walkway is 4 m, and it is moving in the direction shown at 3 m/s. If Mr. Q’s walking speed is 2 m/s, how far away will he be from point B when he reaches the other side?

1. 12 m  
2. 7 m  
3. 6 m  
4. 5 m  
5. 4 m  
6. 3 m  
7. 1 m  
8. None of the Above
Figure A10: Mechanics Clicker Question Sequence A10

(a) Which figure shows $\mathbf{A} + \mathbf{B}$?

(b) Which figure shows $\mathbf{A} - \mathbf{B}$?

(c) Which figure shows $2\mathbf{A} - \mathbf{B}$?
A car rounds a circle while maintaining a constant speed. At the instant shown below, is there an acceleration on the car as it rounds the curve?

1. No, because its speed is constant.
2. Yes.
3. Not enough information is given to answer this question.

A car rounds a circle while maintaining a constant speed. Which arrow represents the direction of the net force on the car as it rounds the curve at the instant shown below?

1. 28
2. 37
3. 465
4. Zero Net Force

You are sitting in the back seat of a taxi. The taxi driver makes a very sharp turn to the left, but maintaining a constant speed. Because you did not wear the seat belt, you begin to slide to the right. Which of the following forces acted on you to slide you to the right?

1. Centripetal force to the right
2. Centripetal force to the left
3. Friction force to the right
4. Friction force to the left
5. There was no force that made you slide to the right.

Continued
You are sitting in the back seat of a taxi. The taxi driver makes a very sharp turn to the left, but maintaining a constant speed. Because you did not wear the seat belt, you slide to the right and press against the door. Which of the following forces acts on you as you are pressed against the door?

1. Centripetal force to the right
2. Centripetal force to the left
3. Friction force to the right
4. Friction force to the left
5. There is no force.
A ball is rolled off the edge of a table that is 1 meter high. It lands on the floor 0.8 meters away from the edge of the table. At the exact moment another ball rolls off the edge of the table, ball X is released from rest at a height of 1.0 meters from the floor. Which ball will hit the floor first?

1. The ball that rolled off.
2. The ball that was dropped.
3. They will both hit at the same time.
4. You can't tell from the info given.

The same ball is rolled off the edge of the 1 meter high table again. This time it is rolling faster so it lands on the floor farther away from the table at 1.5 meters away from the edge of the table. If another ball is again released from rest at a height of 1.0 meters the instant the first ball rolls off the table, which ball will hit the floor first?

1. The ball that rolled off.
2. The ball that was dropped.
3. They will both hit at the same time.
4. You can't tell from the info given.

The same ball is rolled off the edge of the 1 meter high table again. This time it is rolling faster so it lands on the floor farther away from the table at 1.5 meters away from the edge of the table. If another ball is again thrown straight down from a height of 1.0 meters the instant the first ball rolls off the table, which ball will hit the floor first?

1. The ball that rolled off.
2. The ball that was thrown down.
3. They will both hit at the same time.
4. You can't tell from the info given.
A polar bear is sitting on a sheet of ice that is being carried by the current away from the north pole at a speed of 1 m/s. A fish is swimming toward the north pole at a speed of 10 m/s relative to the current. What is the speed of the fish with respect to the bear?

1. 0 m/s
2. 1 m/s
3. 9 m/s
4. 10 m/s
5. 11 m/s
6. 12 m/s

A polar bear is sitting on a sheet of ice that is being carried by the current away from the north pole at a speed of 1 m/s. A fish is swimming toward the north pole at a speed of 10 m/s relative to the current. What is the speed of the fish with respect to the north pole?

1. 0 m/s
2. 1 m/s
3. 9 m/s
4. 10 m/s
5. 11 m/s
6. 12 m/s

Figure A.13: Mechanics Clicker Question Sequence A13
A steel ball is launched from ground level on a no-wind day. (Air drag can be neglected for this problem.) To hit a small steel can permanently attached to scaffolding near the top of a neighboring tower, the launcher must:

1. point at the can.
2. point above the can.
3. point below the can.
4. Not enough information is given.

Again, neglect air drag. On a no-wind day, a heavy small can is released from a tower at the exact instant that a steel ball is launched from ground level at a position not directly below the can. For the ball to hit the can, the launcher must

1. point at the can.
2. point above the can.
3. point below the can.
4. Not enough information is given.

Again, neglect air drag. A small heavy can is released from the tower at the same instant that a steel ball is launched from ground level at a position not directly below the can. To hit the can, if the launch speed is decreased (but still large enough to hit the can) the launch angle $\theta$ must:

1. increase.
2. decrease.
3. remain the same.
4. Not enough information is given.

Figure A14: Mechanics Clicker Question Sequence A14
A battleship simultaneously fires two shells with the same initial speed at enemy ships. If the shells follow the parabolic trajectories shown, which trajectory corresponds to the shell fired with a higher initial vertical velocity?

1. A
2. Both have the same initial vertical velocity.
3. B
4. Not enough info is given.

A battleship simultaneously fires two shells with the same initial speed at enemy ships. If the shells follow the parabolic trajectories shown, which ship gets hit first?

1. A
2. Both are hit simultaneously.
3. B
4. Not enough info is given.

A battleship simultaneously fires two shells with different initial speeds at enemy ships. If the shells follow the parabolic trajectories with same maximum height as shown below, which ship gets hit first?

1. A
2. Both are hit simultaneously.
3. B
4. Not enough info is given.
Figure A.16: Mechanics Clicker Question Sequence A16

A metal ball is dropped and hits the ground. Just after the ball hits the ground and is still rapidly moving downward, what is the relationship between the magnitudes of the force $F_{BG}$ exerted on the ball by the ground and the force $F_{GB}$ exerted on the ground by the ball?

1. $F_{BG} > F_{GB}$
2. $F_{BG} < F_{GB}$
3. $F_{BG} = F_{GB}$
4. Can’t tell from the information given.

A metal ball is dropped and hits the ground. When the ball has penetrated well into the ground but hasn’t yet stopped, what is the relationship between the magnitudes of the force $F_{BG}$ exerted on the ball by the ground and the force $F_{GB}$ exerted on the ground by the ball?

1. $F_{BG} > F_{GB}$
2. $F_{BG} < F_{GB}$
3. $F_{BG} = F_{GB}$
4. Can’t tell from the information given.

A metal ball is dropped, hits the ground, and eventually **comes to a stop**. Now, what is the relationship between the magnitudes of the force $F_{BG}$ exerted on the ball by the ground and the force $F_{GB}$ exerted on the ground by the ball?

1. $F_{BG} > F_{GB}$
2. $F_{BG} < F_{GB}$
3. $F_{BG} = F_{GB}$
4. Can’t tell from the information given.
A cart with mass $m_2$ is connected to a mass $m_1$ using a string that passes over a frictionless pulley, as shown below. Initially, the cart is held motionless. The tension in the string is

1. $m_1 g$
2. $m_2 g$
3. $(m_1 + m_2) g$
4. $(m_1 - m_2) g$
5. Cannot tell from the information given

A cart with mass $m_2$ is connected to a mass $m_1$ using a string that passes over a frictionless pulley, as shown below. Initially, the cart is held motionless. After the cart is released, the tension in the string

1. Increases.
2. Decreases.
3. Remains the same.
4. Cannot tell from the information given.

Figure A.17: Mechanics Clicker Question Sequence A17
(a) A student is riding an elevator in the Acme Building, and the elevator is moving a constant upward speed. Which plot shows the tension \(T\) in the elevator cable as a function of time?

![Graphs of T vs. t](a), (b), (c), (d)

(b) A student steps onto a bathroom scale in a stationary elevator on the first floor of the Acme Building. The elevator accelerates until it reaches the second floor and then continues at constant speed until the 5th floor, where it starts slowing and stops on the 6th floor. Which sketch of weight shown on the scale vs. time during the entire process is most likely to be correct?

![Graphs of W vs. t](a), (b), (c), (d)

(c) Starting from rest, an elevator accelerates uniformly between the 1st and 2nd floors, and decelerates uniformly between the 5th and 6th floors, coming to a stop at the 6th floor. In between, the elevator covers the 6 meter distance between two adjacent floors in 1 sec. Inside, Liz (who is about to graduate), is standing on a scale that reads 800 N when the elevator isn’t moving. What was her minimum scale reading during the trip? (Use \(g = 10 \text{ m/s}^2\))

1. 800 N
2. 420 N
3. 560 N
4. 380 N
5. 640 N
6. 240 N

Figure A.18: Mechanics Clicker Question Sequence A18
Figure A.19: Mechanics Clicker Question Sequence A19

(a) A block sits at rest on a frictionless surface. Which of the following sketches most closely resembles the correct freebody diagram for all forces acting on the block? Each red arrow represents a force. Observe their number and direction, but ignore their lengths.

(b) Now, the same block moves with a constant velocity to the right on the frictionless surface. Which of the following most closely resembles the correct freebody diagram for all forces acting on the block?

(c) Now, the block moves with a constant velocity to the right on a surface that has friction. Which of the following most closely resembles the correct freebody diagram for all forces acting on the block?

1. A
2. B
3. C
4. D
5. None of the above
A block sits at rest and stays at rest on a slide with frictional surfaces. Which of the following sketches most closely resembles the correct freebody diagram for all forces acting on the block? Each red arrow represents a force. Observe their number and direction, but ignore their lengths.

The block sits at rest and stays at rest on the slide. What is the direction of the sum of all forces, (i.e. the resultant force), that the slide exerts on the block?

The block still sits at rest on the slide, held by friction, but now there is no friction between the slide and the ground. The slide

1. Moves to the right
2. Moves to the left
3. Doesn’t move
4. Can move either way.
There is no friction between the slide and the ground. The slide is held at rest until the block reaches its terminal speed (sliding with a constant speed). Then, the slide is released. Afterward, the slide

1. Moves to the right.
2. Moves to the left.
3. Doesn’t move.
4. Can move either way.
Tom pushes two identical blocks on a horizontal frictionless table from the left. The force that block 1 exerts on block 2 is $F_{12}$. The force that block 2 exerts on block 1 is $F_{21}$. Compare the magnitude of $F_{12}$ and $F_{21}$.

1. $F_{12} < F_{21}$
2. $F_{12} = F_{21}$
3. $F_{12} > F_{21}$
4. Cannot be determined

Tom now pushes eight identical blocks on the horizontal and frictionless table (he’s compulsive). The force that block 1 exerts on block 2 is $F_{12}$; the force that block 7 exerts on block 8 is $F_{78}$. What is the ratio $F_{12}/F_{78}$?

1. 8
2. 1/8
3. 1
4. 7
5. 1/7

Figure A.21: Mechanics Clicker Question Sequence A21
Robert lifts the blue box, which weighs 1000 N, just a little way off the ground and holds it for 2 minutes, as shown. With what force does he have to pull on the rope to hold the box off the ground?

1. 0 N
2. 500 N
3. 1000 N
4. 2000 N
5. None of the Above

Now, Robert pulls on the rope at an angle. With what force does he have to pull on the rope to hold the box off the ground?

1. 0 N
2. 50 N
3. 500 N
4. 700 N
5. 1000 N
6. 1400 N
7. 2000 N
8. None of the Above

Robert again lifts the 1,000 N weight just a little off the ground using a new technique as shown below. With what force does he have to pull on the rope to hold the box off the ground?

1. 0 N
2. 87.15 N
3. 174.3 N
4. 996.2 N
5. 1000 N
6. 1992 N
7. 2000 N
8. None of the Above

Figure A.22: Mechanics Clicker Question Sequence A20

Continued
Robert now uses two pulleys to lift the 1000 N weight just a little off the ground as shown. With what force does he have to pull down on the rope attached to the smaller pulley to hold the box off the ground?

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>1.</td>
<td>0 N</td>
</tr>
<tr>
<td>2.</td>
<td>250 N</td>
</tr>
<tr>
<td>3.</td>
<td>500 N</td>
</tr>
<tr>
<td>4.</td>
<td>1000 N</td>
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<tr>
<td>5.</td>
<td>1500 N</td>
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<tr>
<td>6.</td>
<td>2000 N</td>
</tr>
<tr>
<td>7.</td>
<td>None of the Above</td>
</tr>
</tbody>
</table>

Diagram: Frictionless pulley at the top, 1000 N weight at the bottom, frictionless pulley in the middle.
Man A (70kg) and Man B (90kg) are hanging motionless from a roof. What is the tension, $T_A$, in the top rope? (Assume the ropes are massless and use $g = 10 \text{ m/s}^2$.)

1. 0 N
2. 200 N
3. 700 N
4. 900 N
5. 1600 N
6. None of the Above

If you cut the rope between Man A and Man B so that Man A stays motionless, what is the tension, $T_A$, in the top rope? (Assume the ropes are massless and use $g = 10 \text{ m/s}^2$. Ignore any oscillations resulting from cutting the rope.)

1. 0 N
2. 200 N
3. 700 N
4. 900 N
5. 1600 N
6. None of the Above

If you cut the rope between Man A and the roof, what is the tension, $T_B$, in the bottom rope? (Assume the ropes are massless and use $g = 10 \text{ m/s}^2$. Ignore any oscillations resulting from cutting the rope.)

1. 0 N
2. 200 N
3. 700 N
4. 900 N
5. 1600 N
6. None of the Above

Continued
Figure A.23 continued

Man A (70 kg) and Man B (90 kg) are hanging motionless from a platform at rest. What is the tension, $T_A$, in the top rope if the platform accelerates upward at a constant rate of 2 m/s$^2$? (Assume the ropes are massless and use $g = 10$ m/s$^2$.)

1. 0 N
2. 200 N
3. 700 N
4. 840 N
5. 900 N
6. 1600 N
7. 1740 N
8. 1920 N
9. None of the Above
A small guy and a large football player moving at the same speed collide head-on. Which person experiences the larger average force during the collision?

1. The small guy experiences the larger force.
2. The football player experiences the larger force.
3. Both experience the same force.
4. Can’t tell without more information.

A small guy and a large football player moving at the same speed collide head-on. Which person undergoes the larger acceleration during the collision?

1. The small guy.
2. The accelerations are the same.
3. The football player.
4. Can’t tell without knowing the final velocity of the total mass.

A small guy moving at a high speed collides with a stationary large football player. Now, which person experiences the larger average force during the collision?

1. The small guy experiences the larger force.
2. The football player experiences the larger force.
3. Both experience the same force.
4. Can’t tell without more information.

Figure A.24: Mechanics Clicker Question Sequence A24
A 50 kg person stands on a 25 kg platform. He pulls on the rope that is attached to the platform via the frictionless pulley system shown below. With what force does he have to pull on the rope to move the platform up at a steady rate? (Ignore friction and assume g = 10 m/s²)

1. 750 N
2. 625 N
3. 500 N
4. 250 N
5. 75 N
6. 50 N
7. 25 N
8. Impossible to determine

A 50 kg person stands on a 25 kg platform. Another man on the ground pulls on the rope that is attached to the platform via the frictionless pulley system shown below. With what force does he have to pull on the rope to move the platform up at a steady rate? (Ignore friction and assume g = 10 m/s²)

1. 750 N
2. 625 N
3. 500 N
4. 375 N
5. 250 N
6. 75 N
7. 50 N
8. 25 N

Figure A.25: Mechanics Clicker Question Sequence A25
A ladybug sits at the outer edge of a merry-go-round, and a gentleman bug sits halfway between her and the axis of rotation. The merry-go-round makes a complete revolution once each second. (Assume non-zero frictional force and the same coefficients of friction for both bugs.) The gentleman bug’s speed is

1. Half the ladybug’s
2. The same as the ladybug’s
3. Twice the ladybug’s
4. Impossible to determine

A ladybug sits at the outer edge of a merry-go-round, and a gentleman bug sits halfway between her and the axis of rotation. Then, the turntable very slowly starts rotating ever more rapidly. What is the first event that will occur? (Assume non-zero frictional force and the same coefficients of friction for both bugs.)

1. The ladybug will slide into the gentleman bug.
2. The gentleman bug will slide into the ladybug.
3. The ladybug falls off
4. The gentleman bug falls off.

Now, the turntable stops rotating, and the ladybug and the gentleman bug move to opposite edges of the outer rim. The gentleman bug has not watched his weight and is much more massive. The turntable then begins rotating ever more rapidly. Who will fall off first? (Assume non-zero frictional force and the same coefficients of friction for both bugs.)

1. The ladybug
2. The gentleman bug
3. Both will fall off at about the same time.
4. Not enough information to determine
Bob the block is placed next to the cylindrical glass wall of an amusement park ride. The cylinder then begins spinning with a constant angular velocity, and spinning Bob remains stuck to the wall even when the floor drops away. The free-body diagram of all forces acting on Bob looks like:

1. A
2. B
3. C
4. D
5. None of the above

In a physics lab, you place a block on the top of a low-friction ramp. The block slides down the ramp, around a circular part at the bottom, up a ramp on the other side, and then shoots off the end. Is the net force on the block zero at any of the points A, B, C or D?

1. A
2. B
3. C
4. D
5. None of the above.

Figure A.27: Mechanics Clicker Question Sequence A27
A car of mass $M$ is moving on a highway. The driver applies the brakes and the car starts to slide. Assuming a coefficient of kinetic friction $\mu_k$, what is the car’s acceleration?

1. $-\mu_k M$
2. $-\mu_k g$
3. $-M g$
4. $-\mu_k M g$
5. Not enough information to determine

Two vehicles of mass $M$ and $2M$ are moving in the same direction on a highway. Both drivers apply their brakes at the same time and both vehicles begin sliding. If the coefficient of kinetic friction $\mu_k$ is the same for both vehicles, how do their accelerations $a_1$ and $a_2$ compare?

1. $a_1$ is twice $a_2$
2. $a_1$ is the same as $a_2$
3. $a_1$ is half $a_2$
4. Not enough information to determine

Two vehicles of mass $M$ and $2M$ are moving in the same direction and speed on a highway. Both drivers apply their brakes at the same time and both vehicles begin sliding. If the coefficient of kinetic friction $\mu_k$ is the same for both vehicles, which vehicle stops first?

1. The less massive one
2. The more massive one
3. Both stop at the same time
4. Not enough information to determine

Figure A.28: Mechanics Clicker Question Sequence A28
In a physics lab, a pendulum hung from the ceiling slowly swings back and forth. Select the arrow pointing closest to the direction of its acceleration when it is at its lowest at point C.


In a physics lab, a pendulum hung from the ceiling slowly swings back and forth. Select the arrow closest to the direction of its acceleration when it is at its maximum height at point A.


In a physics lab, a pendulum hung from the ceiling slowly swings back and forth. Select the arrow closest to the direction of its acceleration when it is halfway down at point B.


Figure A.29: Mechanics Clicker Question Sequence A29
In a physics lab, a pendulum hung from the ceiling swings back and forth. Select the arrow pointing closest to the direction of the net force (sum of all forces) acting on the pendulum bob when it is at its lowest at point C.

A. Zero net force.
Bill whirls a ball attached to a string in a **horizontal plane** around his head. The string breaks exactly when the ball’s velocity points in the direction of a tree trunk. Will the ball continue along path D and hit the tree, or along one of the other paths and miss the tree?

In a physics lab, a pendulum hung from the ceiling swings back and forth. Suddenly, the string breaks as the pendulum bob reaches its lowest point from the left. Which path will the pendulum bob most likely take after the string breaks?

In a physics lab, a pendulum hung from the ceiling swings back and forth. Suddenly, the string breaks as the pendulum bob reaches its lowest point from the left. Which arrow best represents the direction of the pendulum bob’s velocity immediately after the string breaks?

---

Figure A.30: Mechanics Clicker Question Sequence A30
A battleship simultaneously fires two identical shells with the same initial speed at enemy ships. If the shells follow the trajectories shown and hit the enemy ships at the same height above sea level, which shell has the greater final speed just before it hits the enemy ship? (Ignore air resistance.)

1. Shell A.
2. Both have the same final speed.
3. Shell B.
4. Not enough information is given.

A battleship simultaneously fires two identical shells with the same initial speed at enemy ships. If the shells follow the trajectories shown and hit the enemy ships at the same height above sea level, which shell has the larger kinetic energy just before it hits the enemy ship? (Ignore air resistance.)

1. Shell A.
2. Both have the same kinetic energy.
3. Shell B.
4. Not enough information is given.

Three cannons are arranged as shown below so that they shoot identical balls simultaneously with the same initial speed \( v \) from the same height. Which one reaches the ground below first? (Ignore air resistance.)

1. Ball A.
2. Ball B.
3. Ball C.
4. All of them hit simultaneously.
5. Not enough information is given.

Figure A.31: Mechanics Clicker Question Sequence A31
A sports car accelerates from rest. Assume that power of the engine is independent of velocity and neglect air drag, etc. Which of the following graphs best represents the speed of the car as a function of time.

1. A
2. B
3. C
4. D

A sports car accelerates from zero to 30 mph in 1.5 s. How long would it take to accelerate from zero to 60 mph, assuming the power of the engine to be independent of velocity and neglecting air drag?

1. 2 s
2. 3 s
3. 4.5 s
4. 6 s
5. 9 s
6. 12 s

Figure A.32: Mechanics Clicker Question Sequence A32
A car traveling to the right with a speed $v$ brakes to a stop in a distance $d$. What is the work done on the car by the frictional force $F$? (Assume that the frictional force is constant).

\[ W = F \cdot d \]

1. $W = F \cdot d$
2. $W = -F \cdot d$
3. $W = 0$
4. $W = F \cdot v$
5. $W = -F \cdot v$

A car travels with a constant velocity $v$ for a distance $d$ up a hill that makes an angle $\theta$ with respect to the horizontal. What is the work done by the sum of the gravitational force plus the constant upward frictional force $F$ that the hill exerts on the tires of the car?

\[ W = (mgsin\theta) \cdot d \]

1. $W = (mgsin\theta) \cdot d$
2. $W = -(mgsin\theta) \cdot d$
3. $W = 0$
4. $W = Fd$
5. $W = -Fd$

A satellite travels with a constant speed $|v|$ as it moves around a circle centered on the earth. How much work is done by the gravitational force $F$ on the satellite after it travels half way around the earth in time $t$?

\[ W = F \cdot |v|t \]

1. Cannot be determined
2. $W = 0$
3. $W = F \cdot |v|t$
4. $W = -F \cdot |v|t$

Figure A.33: Mechanics Clicker Question Sequence A33
The engine of a 1000 kg sports car rotates the tires, creating a forward pushing force $F$ on the tires of the car that varies as a function of distance. The force is shown below. If the car starts at rest, what is the speed of the car after traveling 500 meters?

1. 0 m/s
2. 71 m/s
3. 100 m/s
4. 141 m/s
5. 200 m/s
A car traveling to the right with a speed $v$ brakes to a stop in a distance $d$. The work done on the car by the frictional force $F$ is: (Assume that the frictional force is constant).

1. $W = Fd$
2. $W = -Fd$
3. $W = 0$
4. $W = Fv$
5. $W = -Fv$

A lighter car and a heavier truck, each traveling to the right with the same speed $v$, hit the brakes. The retarding frictional force $F$ on both cars turns out to be the same constant. After both vehicles travel a distance $d$ (and both are still moving), which of the following statements is true?

1. The work done on both vehicles is the same.
2. The average power expended is the same.
3. They will have the same velocity.
4. They will have the same kinetic energy.
5. They will traverse the distance $d$ in the same time.

A lighter car and a heavier truck, each initially at rest, are pushed with the same constant force $F$. After both vehicles travel a distance $d$, which of the following statements is true? (Ignore friction)

1. The average power expended is the same.
2. They will have the same velocity.
3. They will have the same kinetic energy.
4. There's not enough information to answer.

Figure A.34: Mechanics Clicker Question Sequence A34
Figure A.35: Mechanics Clicker Question Sequence A35

An 800 kg car traveling to the right experiences a positive frictional force from the road as shown in the graph. Forces to the right are positive. While traveling the full 900 meters, the car’s speed:

1. first increases and then decreases.
2. first decreases and then increases.
3. continuously increases.
4. drops to zero at 900 m.
5. None of the above.

An 800 kg car traveling to the right experiences a positive frictional force from the road as shown in the graph. Forces to the right are positive. What happens to the cumulative work done on the car by the frictional force, while traveling the full 900 meters?

1. first increases and then decreases.
2. first decreases and then increases.
3. is zero.
4. Continuously decreases.
5. None of the above.

An 800 kg car initially at rest at 0 meters subsequently experiences a positive frictional force from the road as shown in the graph. Forces to the right are positive. At 900 meters, the car’s velocity is:

1. 17 m/s.
2. 24 m/s.
3. 31 m/s.
4. 38 m/s.
5. None of the above.
An 800 kg car initially travelling to the right with a speed of 15 m/s at zero meters subsequently experiences a positive frictional force from the road as shown in the graph. Forces to the right are positive. At 300 meters, the car's velocity is:

1. 17 m/s.
2. 24 m/s.
3. 31 m/s.
4. 38 m/s.
5. None of the above.
Figure A.36: Mechanics Clicker Question Sequence A36
A child starting from rest slides down each of the four frictionless slides A to D. Each has the same vertical height. Rank in order, from largest to smallest, her speeds $v_A$ to $v_D$ at the bottom.

1. $v_A = v_B = v_C = v_D$
2. $v_D > v_A = v_B > v_C$
3. $v_D > v_A > v_B > v_C$
4. $v_C > v_A = v_B > v_D$
5. $v_C > v_B > v_A > v_D$

Two identical balls with different initial speeds slide down two frictionless tracks of the same height but different angles, and then reach the bottom. Which of the following quantities is (are) equal for these two processes?

1. The work done by the earth
2. The change of the ball’s kinetic energy
3. The change of the ball’s speed
4. Both (1) and (2)
5. Both (1) and (3)
6. Both (2) and (3)
7. (1), (2), and (3)
8. None of the above

Two balls of different mass, starting from rest, slide down two identical frictionless tracks of the same vertical height, and then reach the bottom. Which of the following quantities is (are) same for these two processes?

1. The work done by the earth
2. The change of the ball’s kinetic energy
3. The change of the ball’s speed
4. Both (1) and (2)
5. Both (1) and (3)
6. Both (2) and (3)
7. (1), (2), and (3)
8. None of the above

Figure A.37: Mechanics Clicker Question Sequence A37
Two balls, one twice as massive as the other, are dropped from the roof of a building (freefall). Just before hitting the ground, the more massive ball has ______ the kinetic energy of the less massive ball. (Neglect air friction.)

1. One half
2. The same
3. Twice
4. Four times

Three balls of equal mass are fired simultaneously with equal speeds from the same height \( h \) above the ground. Ball 1 is fired straight up, ball 2 is fired straight down, and ball 3 is fired horizontally. Rank in order from largest to smallest their speeds \( v_1, v_2, \) and \( v_3 \) an instant before they hit the ground. (Neglect friction.)

1. \( v_1 > v_2 > v_3 \)
2. \( v_3 > v_2 > v_1 \)
3. \( v_2 > v_1 > v_3 \)
4. \( v > v > v \)
5. \( v_1 = v_2 > v_3 \)
6. \( v_1 = v_2 = v_3 \)
7. Need to know height \( h \)

Figure A.38: Mechanics Clicker Question Sequence A38
The graph shows the magnitude of the spring force versus displacement plots for three springs. Rank in order, from largest to smallest, the spring constants $k_1$, $k_2$, and $k_3$.

1. $k_3 > k_2 > k_1$
2. $k_1 = k_3 > k_2$
3. $k_2 > k_1 = k_3$
4. $k_1 > k_2 > k_3$
5. $k_1 > k_3 > k_2$

A spring-loaded gun shoots a plastic ball with a speed of 4 m/s. If the spring is compressed twice as far, the ball's speed will be

1. 16 m/s.
2. 8 m/s.
3. 4 m/s.
4. 2 m/s.
5. 1 m/s.

A spring-loaded toy dart gun shoots a dart to a maximum height of 24 meters. The same dart is again shot upward, but this time the spring is compressed only half as far before firing. Neglecting friction and assuming an ideal spring, how far up does the dart go this time?

1. 96 m
2. 48 m
3. 24 m
4. 12 m
5. 6 m
6. 3 m

Figure A.39: Mechanics Clicker Question Sequence A39
A block attached to a spring is oscillating between point X (fully compressed) and point Y (fully stretched). As the block moves from point X to O (spring relaxed), the spring does work $W$ on the block. How much work does the spring do on the block as it moves from O to Y?

(a) 
1. 0
2. $W$
3. $-W$
4. $2W$
5. $-2W$
6. $W/2$
7. $-W/2$

(b) 
A block attached to a spring is oscillating between point X (fully compressed) and point Y (fully stretched). As the block moves from point X to O (spring relaxed), the spring does work $W$ on the block. How much work does the spring do on the block as it moves from X to Y?

1. 0
2. $W$
3. $-W$
4. $2W$
5. $-2W$
6. $W/2$
7. $-W/2$

(c) 
A block attached to a spring is oscillating between point X (fully compressed) and point Y (fully stretched). As the block moves from point X to O (spring relaxed), the spring does work $W$ on the block. How much work does the spring do on the block as it moves from X to O after several oscillations?

1. 0
2. $W$
3. $-W$
4. $2W$
5. $-2W$
6. $W/2$
7. $-W/2$

Figure A.40: Mechanics Clicker Question Sequence A40
A block attached to a spring is oscillating between point $X$ (fully compressed) and point $Y$ (fully stretched). At point $X$, which of the following quantities would reach its maximum value?

1. The block's kinetic energy
2. The spring potential energy
3. The magnitude of the block's momentum
4. The magnitude of the block's acceleration
5. Both 1 and 3
6. Both 2 and 4
7. None of the above

A block attached to a spring is oscillating between point $X$ (fully compressed) and point $Y$ (fully stretched). At point $O$ (relaxed spring), which of the following quantities would reach its maximum value?

1. The block's kinetic energy
2. The spring potential energy
3. The magnitude of the block's momentum
4. The magnitude of the block's acceleration
5. Both 1 and 3
6. Both 2 and 4
7. None of the above

A block attached to a spring is oscillating between point $X$ (fully compressed) and point $Y$ (fully stretched). At point $Y$, which of the following quantities would reach its maximum value?

1. The block's kinetic energy
2. The spring potential energy
3. The magnitude of the block's momentum
4. The magnitude of the block's acceleration
5. Both 1 and 3
6. Both 2 and 4
7. None of the above

Figure A.41: Mechanics Clicker Question Sequence A41
A large skinny guy with mass $2M$ and a smaller guy with mass $M$ are holding onto a massless pole while standing on frictionless ice, as shown below. If the big guy pulls himself toward the little guy, where would they meet?

1. -3 m  
2. -2 m  
3. -1 m  
4. 0 m  
5. 1 m  
6. 2 m  
7. 3 m  
8. None of the above

A large skinny guy with mass $2M$ and a smaller guy with mass $M$ are holding onto a massless pole while standing on frictionless ice, as shown below. If the little guy pulls himself toward the big guy, where would they meet?

1. -3 m  
2. -2 m  
3. -1 m  
4. 0 m  
5. 1 m  
6. 2 m  
7. 3 m  
8. None of the above

Three tiny equal-mass magnets are placed on a horizontal frictionless surface at the corners of an equilateral triangle (all sides 2 m and all angles $60^\circ$). When the magnets are released, they attract and quickly slide to a single point. What are the $x$ and $y$ coordinates of that point? (Before release, the $y$-axis passed through the top ball and the $x$-axis passed through the bottom balls.)

<table>
<thead>
<tr>
<th>$x$</th>
<th>$y$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 m</td>
<td>0 m</td>
</tr>
<tr>
<td>0 m</td>
<td>1 m</td>
</tr>
<tr>
<td>0 m</td>
<td>.58 m</td>
</tr>
<tr>
<td>0 m</td>
<td>.87 m</td>
</tr>
<tr>
<td>.67 m</td>
<td>.67 m</td>
</tr>
<tr>
<td>0 m</td>
<td>.67 m</td>
</tr>
</tbody>
</table>

Figure A.42: Mechanics Clicker Question Sequence A42
A constant force is exerted on a cart that is initially at rest on a frictionless air track. The force acts for a short time interval and gives the cart a final speed. To reach the same speed using a force that is half as big, the force must be exerted for a time interval that is:

1. Four times as long.
2. Twice as long.
3. The same length.
4. Half as long.
5. A quarter as long.

Two carts—A and B—on frictionless air tracks are initially at rest. Cart A is twice as massive as cart B. Now you exert the same constant force on both carts for 1 second. One second later, the momentum of cart A is:

1. Twice the momentum of cart B
2. The same as the momentum of cart B
3. Half the momentum of cart B
4. Not enough information to determine

Two identical carts, A and B, initially are moving on frictionless air tracks. The initial speed of cart A is twice as that of cart B. You then exert the same constant force on the two carts over 1 second. One second later, the change in momentum of cart A is:

1. Non-zero and twice the change in momentum of cart B
2. Non-zero and the same as the change in momentum of cart B
4. Non-zero and half the change in momentum of cart B
5. Not enough information to determine

Figure A.43: Mechanics Clicker Question Sequence A43
(a) Two equal-mass balls swing down and hit identical bricks while traveling at identical speeds. Ball A bounces back, but ball B just stops when it hits the brick. Which ball has a better chance of knocking the brick over?

1. A
2. B
3. They both have the same chance.

(b) A satellite first moves at 20,000 MPH toward the sun. Sometime later, you see that the satellite is now moving at 20,000 MPH away from the sun. As a first-class scientist, you infer that

1. An average force was exerted on the satellite, but there was no net work done on the satellite.
2. The average net force and work done on the satellite were both zero.
3. There was zero average net force but non-zero work done on the satellite.
4. The average net force and work done on the satellite were both non-zero.

(c) Identical constant forces F push identical Blocks A and B from the start line to the finish line. Block A is initially at rest, but block B is initially moving to the right. Which block incurs the greater change in momentum while moving from the start to the finish line?

1. A
2. B
3. Both have the same change in momentum.
4. Can’t tell from the information given.

Figure A.44: Mechanics Clicker Question Sequence A44

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Identical constant forces $F$ push identical Blocks A and B from the start line to the finish line. Both blocks start at rest, but block A has 4 times as much mass as block B. Which block incurs the greater change in momentum while moving from the start to the finish line?

1. A
2. B
3. Both have the same change in momentum
4. Can’t tell from the information given
A wood block rests at rest on a table. A bullet shot into the block stops inside, and the bullet plus block start sliding on the frictionless surface. The momentum of the bullet plus block remains constant

1. When the bullet approaches.
2. When the bullet is slowing down
3. After the bullet stops
4. 1 and 3.
5. 2 and 3.
6. 1 and 2.
7. It never is conserved.
8. It always is conserved.

Two cars initially at rest on a frictionless surface are blown apart by an explosion. The one with twice the mass ends up moving to the right at 10 meters/second. The less massive car ends up moving to the left at what speed?

1. 5 m/s
2. 7 m/s
3. 10 m/s
4. 14 m/s
5. 15 m/s
6. 20 m/s
7. 25 m/s

One cue ball hits an object ball. The cue ball's motion is at a 90 angle to the motion of the object ball after the collision. The ratio of speed of the cue ball after the collision and the object ball is 1:√3 . What is the ratio of the velocity between the initial and final speed of the cue ball? All balls have the same mass.

1. 1:√3
2. 2:1
3. √3 :1
4. 1:1
5. 1:2
6. 1+√3 : √3

Figure A.45: Mechanics Clicker Question Sequence A45
A 20 g bullet is shot with an initial velocity $v$ into a 5 kg wood block attached to the ceiling with massless strings. The collision happens so rapidly that the block doesn't change position appreciably until after the bullet stops. When does the momentum of the bullet plus block remain constant?

1. When the bullet approaches.
2. When the bullet stops.
3. When the block swings upward.
4. 1 and 3.
5. 2 and 3.
6. 1 and 2.
7. It never is conserved.
8. It always is conserved.

A 20 gram bullet with an unknown velocity $v$ is shot into a 5 kg wood block attached to a pivot with massless strings. What percentage of the original mechanical energy is left after the collision process? (The remainder of the energy is converted into non-mechanical forms of energy such as thermal energy.)

1. 0%.
2. 0.4%.
3. 50%.
4. 94%.
5. 99.6%.
6. None of the above.

A 20 gram bullet with an initial velocity $v$ is shot into a 5 kg wood block attached to the ceiling with massless strings. While the block with the bullet stuck inside is swinging upward, which of the following quantities is conserved?

1. Momentum.
2. Velocity.
3. Acceleration.
4. Kinetic energy.
5. Kinetic plus potential energy
6. 1 and 5
7. 2 and 5
8. 1, 2, and 5
9. None of the above.

Figure A.46: Mechanics Clicker Question Sequence A46
A 20 gram bullet with an initial velocity $v$ is shot into a 5 kg wood block attached to a pivot with massless strings. After the collision, the block swings upward to a maximum height $h = 0.2\text{m}$ above its initial position. What was the initial velocity of the bullet?

1. 31 m/s.
2. 44 m/s.
3. 248 m/s.
4. 497 m/s.
5. 994 m/s
6. None of the above.
A car with a mass M is moving toward another car with a mass 2M on a frictionless surface. Both cars have a speed of 10 m/s. Subsequently, they collide and stick together. What is the final velocity of the two car system?

1. 0 m/s
2. +3.3 m/s
3. -3.3 m/s
4. +5.0 m/s
5. -5.0 m/s
6. +10 m/s
7. -10 m/s
8. None of the above

Two cars initially at rest on a frictionless surface are blown apart by an explosion. The one with twice the mass ends up moving to the right at 10 meters/second. The less massive car ends up moving to the left at what speed?

1. 5 m/s
2. 7 m/s
3. 10 m/s
4. 14 m/s
5. 15 m/s
6. 20 m/s
7. 25 m/s

A rocket ship parked at rest in space suddenly explodes into 3 equal-mass pieces traveling in the directions shown. If the piece traveling upward has a speed of 150 m/s, what are the speeds of the two other two pieces?

1. Both are at 150 m/s
2. Both are at 300 m/s
3. Both are at 600 m/s
4. Both are at 900 m/s
5. Both are at 1200 m/s
6. Both are at 1500 m/s
7. They each have different speeds
8. None of the Above
Suppose you are on a cart initially at rest that rides on a frictionless track. If you throw a ball off the cart towards the left, will the cart be put into motion?

1. Yes, and it moves to the right.
2. Yes, and it moves to the left.
3. No, it remains in place.

Suppose you are on a cart which is initially at rest that rides on a frictionless track. You throw a ball at a vertical surface that is firmly attached to the cart. If the ball bounces straight back as shown in the picture, will the cart be put into motion after the ball bounces back from the surface?

1. Yes, and it moves to the right.
2. Yes, and it moves to the left.
3. No, it remains in place.

Suppose you are on a cart that is moving at a constant speed \( v \) toward the left on a frictionless track. If you throw a massive ball straight up (from your perspective), how will the speed of the cart change?

1. Increase
2. Decrease
3. Will not change
4. You need to know how fast you throw the ball
Which figure shows \( \vec{A} - \vec{B} \)?

A moving marble ball hits a hard surface and changes direction. The initial velocity \( \vec{v}_i \) and the final velocity \( \vec{v}_f \) of the marble are shown in the diagram. Which arrow best represents the change in velocity of the marble?

A moving marble hits a surface and changes direction. The initial velocity \( \vec{v}_i \) and the final velocity \( \vec{v}_f \) of the marble are shown in the diagram. Which arrow shows the direction of the impulse on the marble due to the wall?

Figure A.49: Mechanics Clicker Question Sequence A49
Two 1 kg wheels with fixed hubs start from rest, and forces are applied as shown. Assume that the hub and spokes are massless, and that $F_1 = 1$ N. In order to impart identical angular accelerations, how large must $F_2$ be?

- $M = 1$ kg
- $R_1 = 0.5$ m
- $R_2 = 1.0$ m

1. 0.25 N
2. 0.50 N
3. 1 N
4. 2 N
5. 4 N

Two 1 kg wheels with fixed hubs start from rest and equal-magnitude 1 N forces are applied to each. The hub and spokes are virtually massless. In order to impart identical angular accelerations, at what angle $\theta$ must $F_1$ be applied with respect to horizontal?

- $|F_1| = 1$ N
- $|F_2| = 1$ N
- $M = 1$ kg
- $R_1 = 0.5$ m
- $R_2 = 1.0$ m

1. 0°
2. 15°
3. 30°
4. 45°
5. 60°
6. 90°

You are given the same small wheel and force as in the previous problem. As before, the spokes and hub are virtually massless. What is the magnitude of the wheel’s angular acceleration?

- $|F| = 1$ N
- $\Theta = 60°$ wr to horizontal
- $M = 1$ kg
- $R = 0.5$ m

1. $\frac{\pi}{4}$ rad/sec$^2$
2. $\frac{\pi}{8}$ rad/sec$^2$
3. 1 rad/sec$^2$
4. 2 rad/sec$^2$
5. 4 rad/sec$^2$
A mass M is uniformly distributed over the length L of a thin rod. The mass inside a short element $dx$ is given by:

$$M = \frac{M}{L} dx$$

1. $\frac{M}{L}$
2. $\frac{M}{L} dx$
3. $M dx$
4. $M dx$
5. None of the above.

A mass M is uniformly distributed over the length L of a thin rod. The contribution to the moment of inertia by a short element $dr$ is given by:

$$I = r^2 M dr$$

1. $r M dr$
2. $r \left(\frac{M}{L}\right) dx$
3. $r \left(\frac{M}{L}\right)$
4. $r^2 M$
5. $r M dx$

A mass M is uniformly distributed over the circumference of a thin ring with radius r. The moment of inertia for this ring when rotating about its center is:

1. Cannot be determined without integrating.
2. $M r$
3. $\frac{1}{2} M r$
4. $M r^2$
5. $\frac{1}{2} M r^2$
A mass $M$ is uniformly distributed over a disk of radius $R$ and area $\pi R^2$. The area of a thin ring inside the disk with radius $r$ and thickness $dr$ is:

1. $2 \pi r dr$
2. $r dr$
3. $\pi r^2$
4. $\pi r^2 dr$
5. $r^2$

A mass $M$ is uniformly distributed over a disk of radius $R$. The mass contained in a thin ring with radius $r$ and thickness $dr$ inside the disk is given by:

Remember to use a ratio of the ring area to the total area of the disk.

1. $\frac{M}{\pi r^2} dr$
2. $\frac{M}{R} dr$
3. $\frac{M R}{r}$
4. $\frac{2 M}{R} dr$
5. None of the above.
Two objects, a cylinder and a hoop, roll down from the top of a frictional ramp at the same time. They are made of different materials, but both have the same mass and radius. Which one reaches the bottom first?

1. Cylinder
2. Hoop
3. Both reach the bottom at the same time
4. Not enough information to determine

Two cylinders of different size and mass roll down from the top of a frictional ramp at the same time. Which one gets down the ramp first?

1. Larger cylinder
2. Smaller cylinder
3. Both reach the bottom at the same time
4. Not enough information to determine

Two cylinders of different size and mass move down from the top of a frictional ramp at the same time. It is the same question as before, but now the ramp is frictionless. Which one now gets down the ramp first?

1. Large cylinder
2. Small cylinder
3. Both reach the bottom at the same time
4. Not enough information to determine

Continued

Figure A.52: Mechanics Clicker Question Sequence A52
Two cylinders with the same radius and mass start from rest and roll down two hills from the same height. Cylinder 2 has a massless axis with a smaller radius. There is a groove in the hill, so that only the axle touches. Which object reaches the bottom first?

1. 1
2. 2
3. They arrive at the same time.
4. Need to know the axle’s radius.
A disk that initially spins at 2 revolutions/sec is braked uniformly to a stop in ½ second. What is its initial angular speed $\omega_0$?

1. $\pi / s$
2. $2\pi / s$
3. $4\pi / s$
4. $8\pi / s$

A disk that initially spins at 2 revolutions/sec is braked uniformly to a stop in ½ second. What is the value of angular acceleration $\alpha$? (Negative $\alpha$ means stopping)

1. $-4\pi / s^2$
2. $4\pi / s^2$
3. $-8\pi / s^2$
4. $8\pi / s^2$

A disk that initially spins at 2 revolutions/sec is braked uniformly to a stop in ½ second. A bug is stuck on the outer edge 1 meter from the center. How many revolutions does the bug go during the time it takes the disk to stop?

1. 0.25 revolution
2. 0.5 revolution
3. 1 revolution
4. 2 revolution
5. 4 revolution

Figure A.53: Mechanics Clicker Question Sequence A53
Two identical disks rotate about fixed axes with negligible friction. Identical masses are attached to strings wrapped around the axis and the outside rim, respectively, of the two disks. The masses are then released from rest at the same height. Which one takes longer to reach the ground?

1. The mass in system I
2. The mass in system II
3. They hit the ground at the same time.
4. Not enough information to tell.

Two identical disks rotate about fixed axes with negligible friction. Identical masses are attached to strings wrapped around the axis and the outside rim, respectively, of the two disks. The masses are then released from rest at the same height. Just before each mass hits the ground, which mass has more **translational** kinetic energy?

1. Disk I
2. Disk II
3. They have the same translational kinetic energy
4. Not enough information to tell.

Two identical disks rotate about fixed axes with negligible friction. Identical masses are attached to strings wrapped around the axis and the outside rim, respectively, of the two disks. The masses are then released from rest at the same height. Just before each mass hits the ground, which disk has more **rotational** kinetic energy?

1. Disk I
2. Disk II
3. They have the same rotational kinetic energy
4. Not enough information to tell.

Figure A.54: Mechanics Clicker Question Sequence A54
The magnitude of the angular momentum for a freely rotating disk around its center is $L$. You drop a heavy block onto the disk along the direction as depicted below, and the block then stays on the disk. Now the magnitude of the angular momentum for the disk-block system is:

1. $> L$
2. $< L$
3. $= L$
4. Not enough information to determine

The angular speed of a freely rotating disk around its center is $\omega$. You drop a heavy block onto the disk along the direction as depicted below, and the block then stays on the disk. The angular speed of the disk-block system now:

1. decreases
2. increases
3. remains the same
4. Not enough info. to determine

The magnitude of the angular momentum for a freely rotating disk around its center is $L$. You drop a heavy block onto the disk along the direction as depicted below, and the block then stays on the disk. Now the magnitude of the angular momentum for the disk-block system is:

1. $> L$
2. $< L$
3. $= L$
4. Not enough info. to determine

Figure A.55: Mechanics Clicker Question Sequence A55
The non-spinning axle of a rapidly spinning wheel is attached to a non-spinning rod supported by a pole on one end. The direction of spin is such that a point on the wheel is coming at you when it is at the bottom of the wheel and moving away from you when it is at the top. What is the direction of the wheel’s angular momentum? (Use the right-hand rule)

Left: 1. Into the page
2. Out of the page
3. Up (on the page)
4. Down (on the page)
5. Left (on the page)
6. Right (on the page)

The force of gravity on the wheel plus rod is downward. What is the direction of the resulting torque on the wheel-plus-rod system about the pointed support? (The wheel is spinning very rapidly.)

Left: 1. Into the page.
2. Out of the page
3. Up (on the page)
4. Down (on the page)
5. Left (on the page)
6. Right (on the page)

Because of the gravitational force/torque, the wheel-plus-rod system begins to move. Viewed from above, what does it do?

Left: 1. Fall down
2. Rotate clockwise
3. Rotate counterclockwise
4. Not enough information to determine

Figure A.56: Mechanics Clicker Question Sequence A56
Strings are wound around two identical pucks: one is around its outer rim; the other is around its inner rim. You pull both pucks from rest by using the same force $F$. Both pucks start to move on a frictionless surface. Which puck arrives at the finish line first?

1. Puck 1
2. Puck 2
3. Both arrive at the same time
4. Not enough info. to determine

Strings are wound around two identical pucks: one is around its outer rim; the other is around its inner rim. You pull both pucks from rest by using the same force $F$. Both pucks start to move on a frictionless surface. 5 seconds later, which puck has greater center-of-mass speed?

1. Puck 1
2. Puck 2
3. Both have the same C.O.M speed
4. Not enough info. to determine

Strings are wound around two identical pucks: one is around its outer rim; the other is around its inner rim. You pull both pucks from rest by using the same force $F$. Both pucks start to move on a frictionless surface. 5 seconds later, which puck has greater rotational kinetic energy?

1. Puck 1
2. Puck 2
3. Both have the same rotational kinetic energy
4. Not enough info. to determine

Figure A.57: Mechanics Clicker Question Sequence A57
Strings are wound around two identical pucks: one is around its outer rim; the other is around its inner rim. You pull both pucks from rest by using the same force $F$. Both pucks start to move on a frictionless surface. 5 seconds later, which puck has greater total kinetic energy? (Do you know why?)

1. Puck 1  
2. Puck 2  
3. Both have the same total kinetic energy  
4. Not enough info. to determine
Three balls of mass $M$, $2M$, and $5M$ are arranged as shown below. What is the direction of the net gravitational force on the $5M$ mass due to the $M$ and $2M$ masses?

Three balls of mass $M$, $2M$, and $5M$ are arranged as shown below. What is the direction of the net gravitational force on the $2M$ mass due to $M$ and $5M$?

Three balls of equal mass $M$ are arranged at the corners of a triangle as shown below. All sides of the triangle are equal in length. What is the direction of the net gravitational force on the top (red) mass due to the bottom two masses? My goodness, did we let a vector problem sneak in?

Figure A.58: Mechanics Clicker Question Sequence A58
The figure shows a binary star system. The mass of star 2 is twice the mass of star 1. Compared to $F_{\text{1\rightarrow2}}$, the magnitude of the force $F_{\text{2\rightarrow1}}$ is

1. one quarter as big
2. half as big
3. twice as big
4. four times as big
5. the same size

In the binary star system, these two stars usually rotate in circles around a point on the connection line between these two stars. Is this point

1. Near star 1
2. Near star 2
3. Right in the middle of star 1 and star 2
4. Can not be determined

Now, assume the mass for star 2 is 4 times the mass of star 1, Compare the radius of the orbit for star 1 and star 2.

1. $R_1:R_2=1:2$
2. $R_1:R_2=1:4$
3. $R_1:R_2=2:1$
4. $R_1:R_2=4:1$
5. $R_1:R_2=16:1$
Figure A.60: Mechanics Clicker Question Sequence A60
Which satellite has a larger kinetic energy, $K$? Assume orbits are circular and both satellites have the same mass.

1. $K_A < K_B$
2. $K_A > K_B$
3. $K_A = K_B$
4. Cannot be calculated

Which satellite-earth system has a larger potential energy? Assume orbits are circular and both satellites have the same mass.

1. Satellite-earth System A
2. Satellite-earth System B
3. Both have the same potential energy
4. Cannot be calculated

Which satellite-earth system has a larger total energy? Assume orbits are circular and both satellites have the same mass.

1. Satellite-earth System A
2. Satellite-earth System B
3. Both have the same total energy
4. Cannot be calculated
Suppose there was a planet with exactly the same density as earth, but only \( \frac{1}{2} \) the radius. The mass of a uniform sphere is given by \( M = \frac{4}{3} \pi r^3 \rho \), where \( \rho \) is the density.

What would be the ratio of gravity \( g_p/g_e \) for this planet compared to gravity on earth. Note that the mass of the planet would be 8 times smaller than earth.

1. 1/8
2. 1/4
3. 1/2
4. 1
5. 2

Figure A.62: Mechanics Clicker Question Sequence A62
APPENDIX B

CLICKER QUESTION SEQUENCES

FOR

ELECTRICITY & MAGNETISM (E&M)
Two uncharged metal spheres located on top of insulating poles are initially in contact as shown above. A positively charged insulator is brought close to sphere 1 without touching and removed, and then the spheres are separated. What are the signs of the final charges on the two spheres?

<table>
<thead>
<tr>
<th></th>
<th>Q₁</th>
<th>Q₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>+</td>
<td>–</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>–</td>
</tr>
<tr>
<td>3</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>4</td>
<td>+</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>–</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>8</td>
<td>0</td>
<td>+</td>
</tr>
<tr>
<td>9</td>
<td>–</td>
<td>+</td>
</tr>
</tbody>
</table>
Two identical metal balls \( L \) and \( M \) initially have charge 4 C and 0 C, respectively, as shown below. What is the charge on \( M \) after you let \( L \) touch \( M \) and set them apart?

\[ \begin{array}{cc}
L & M \\
+4 \text{ C} & 0 \text{ C}
\end{array} \]

1. 4 C
2. 2 C
3. 1.5 C
4. 1 C
5. 2/3 C
6. 0.5 C
7. 0 C
8. None of the above

Three identical metal balls \( L \), \( M \) and \( N \) initially have charge 4 C, -2 C and 0 C, respectively, as shown below. What is the charge on \( N \) after you let \( L \) first touch \( M \), and then remove \( L \) and let \( M \) touch \( N \)?

\[ \begin{array}{ccc}
L & M & N \\
+4 \text{ C} & -2 \text{ C} & 0 \text{ C}
\end{array} \]

1. 4 C
2. 2 C
3. 1.5 C
4. 1 C
5. 2/3 C
6. 0.5 C
7. 0 C
8. None of the above

Three identical metal balls \( L \), \( M \) and \( N \) initially have charge 4 C, -2 C and 0 C, respectively, as shown below. What is the charge on \( N \) after you let \( L \) first touch \( N \), and then remove \( L \) and let \( M \) touch \( N \)?

\[ \begin{array}{ccc}
L & M & N \\
+4 \text{ C} & -2 \text{ C} & 0 \text{ C}
\end{array} \]

1. 4 C
2. 2 C
3. 1.5 C
4. 1 C
5. 2/3 C
6. 0.5 C
7. 0 C
8. None of the above

Figure B.2: E & M Clicker Question Sequence B2
Two charges, -Q and +2Q are placed a distance R apart. The magnitude and direction of the force F on the -Q charge is shown by the arrow. Which of the following arrows represents the approximate magnitude and direction of the force on the +2Q charge?

(a)

(b)

Two charges, -Q and +2Q are initially placed a distance R apart. The magnitude and direction of the force F on the -Q charge is shown by the arrow in the "Before" picture. Next, the -Q charge is changed to +2Q. Which of the following arrows represents the approximate magnitude and direction of the new force on the bottom +2Q charge?

(c)

Two charges, -Q and +2Q are initially placed a distance R apart. The magnitude and direction of the force F on the -Q charge is shown by the arrow in the "Before" picture. The charges are then moved to a separation distance of R/2. Which arrow's direction and length represents the new force on the +2Q charge?

Figure B.3: E & M Clicker Question Sequence B3
Four equal charges $+Q$ are fixed to the corners of a square, as shown below. Select the direction of the net force on the charge represented by a red circle as shown below.

1. 1
2. 2
3. 3
4. 4
5. 5
6. 6
7. 7
8. 8
9. None of the above

Now, the top and bottom charges are changed to $-Q$, giving the charge distribution shown below. Select the direction of the net force on the charge represented by a red circle as shown below.

1. 1
2. 2
3. 3
4. 4
5. 5
6. 6
7. 7
8. 8
9. None of the above

Finally, the charge represented by the red circle is made negative, but its magnitude isn’t determined. Select the direction of the net force on the charge represented by the red circle.

1. 1
2. 2
3. 3
4. 4
5. 5
6. 6
7. 7
8. 8
9. None of the above

Figure B.4: E & M Clicker Question Sequence B4
(a) Which figure below best shows $\vec{A} + \vec{A}_1 + \vec{A}_2$?

(b) Which figure best shows $2\vec{A} - \vec{B}$?

(c) What are the $x$- and $y$-components $C_x$ and $C_y$ of vector $\vec{C}$?

1. $C_x = -3$ cm, $C_y = 1$ cm
2. $C_x = -4$ cm, $C_y = 2$ cm
3. $C_x = -2$ cm, $C_y = 1$ cm
4. $C_x = -3$ cm, $C_y = -1$ cm
5. $C_x = 1$ cm, $C_y = -1$ cm

Figure B.5: E & M Clicker Question Sequence B5
Tom places a negative charge at the top corner of an isosceles triangle to test the electric field produced by the $+Q$ and $-Q$ charges at the bottom of the triangle. What is the direction of the **net force** on the **top** negative charge?

1. Left.
2. Down.
3. Right.
5. The net force is zero

Now, Tom removes the test charge. What is the direction of the **electric field** at the previous point (top of triangle)?

1. Left.
2. Down.
3. Right.
5. The electric field is zero

Tom never quits. He now wishes to find the direction of the electric field at the origin, as shown by the black dot. The **electric field** at the origin points

1. Left.
2. Down.
3. Right.
5. The net field is zero

Figure B.6: E & M Clicker Question Sequence B6
Figure B.6 continued

Now, Tom changes one of the positive charges on the bottom to negative, as shown below. At the position of the dot, the electric field points approximately
A total charge $Q$ is uniformly distributed over the length $L$ of a line charge distribution. The charge density $\lambda$ is given by

$$\lambda = \frac{Q}{L}.$$ 

1. $\frac{Q}{L}$
2. $\left(\frac{Q}{L}\right)dx$
3. $\frac{Q}{L}$
4. $Q$
5. None of the above.

A total charge $Q$ is uniformly distributed over the length $L$ of a line charge distribution. The total charge inside a short element $dx$ is given by

$$Q_{dx} = \frac{Q}{L} dx.$$ 

1. $\frac{Q}{L}$
2. $\left(\frac{Q}{L}\right)dx$
3. $\frac{L}{\lambda}$
4. $Qdx$
5. None of the above.

A total charge $Q$ is uniformly distributed over the length $L$ of a line charge distribution. The $Y$ component of electric field at point $P$ created by a short element $dx$ is given by:

$$E_y = \frac{kQ_{dx}}{r^2} \times \frac{a}{r} \times \frac{r}{a}$$

1. $\frac{kQ_{dx}}{r^2} \times \frac{a}{r} \times \frac{r}{a}$
2. $\frac{kQ_{dx}}{r^2} \times \frac{x}{r}$
3. $\frac{kQ_{dx}}{L} \times \frac{a}{x}$
4. $\frac{kQ_{dx}}{L} \times \frac{x}{a}$

Figure B.7: E & M Clicker Question Sequence B7
1. The net electric force is zero at point 1.

What is the direction of the electric force on a negative test charge at point 1?

1. 
2. 
3. 
4. 
5. The net electric force is zero at point 1.

(b) Rank the magnitude of the electric field at positions 1, 2, and 3?

1. 1>2>3
2. 1<2<3
3. 2<1<3
4. 1=2<3
5. 1>2=3
6. 1=2=3

(c) At which point, A or B, will the magnitude of the acceleration of a negative test charge be greater if the charge is released from rest, and which way will it go?

1. A and in the direction of the field lines.
2. A and opposite to the field line directions.
3. B and in the direction of the field lines.
4. B and opposite to the field line directions.
5. The accelerations are the same.
A total charge $Q$ is uniformly distributed over a half ring with radius $R$. The total charge inside a small element $d\theta$ is given by:

1. Choice One
2. Choice Two
3. Choice Three
4. Choice Four
5. Choice Five
6. Choice Six

\[ \frac{Q}{2\pi R} d\theta \]
\[ \frac{Q}{\pi R} d\theta \]
\[ \frac{Q}{\pi} d\theta \]
\[ \frac{Q}{2\pi} d\theta \]

A total charge $Q$ is uniformly distributed over a half ring with radius $R$. The $Y$ component of electric field at the center created by a short element $d\theta$ is given by:

1. Choice One
2. Choice Two
3. Choice Three
4. Choice Four

\[ \frac{kQd\theta}{\pi R^2} \sin \theta \]
\[ \frac{kQd\theta}{\pi R^3} \cos \theta \]
\[ \frac{kQd\theta}{\pi R^3} \sin \theta \]
\[ \frac{kQd\theta}{\pi R^3} \cos \theta \]

A total charge $Q$ is uniformly distributed over a ring with radius $R$. Without integration, the magnitude of the total electric field at point $P$ created by this ring is given by:

1. Choice One
2. Choice Two
3. Choice Three
4. Choice Four

\[ \frac{kQ}{R^2} \]
\[ \frac{kQ}{R^2 + Z^2} \]
\[ \frac{kZQ}{R^3} \]
\[ \frac{kZQ}{(R^2 + Z^2)^{3/2}} \]

Figure B.9: E & M Clicker Question Sequence B9
Figure B.10: E & M Clicker Question Sequence B10
A negative charge -2Q is brought near a conducting sphere with a charge +Q at its center. The directions of the forces on the -2Q and +Q charges are:

1. Right on -2Q, left on +Q
2. Zero force on -2Q, left on +Q
3. Zero on both charges
4. Right on -2Q, zero on +Q
5. None of the above.
Figure B.11: E & M Clicker Question Sequence B11

(a) A positive charge is kept (fixed) at the center inside a fixed spherical neutral conducting shell. Which of the following represents the charge distribution on the inner and outer walls of the shell?

1. ![Diagram 1]
2. ![Diagram 2]
3. ![Diagram 3]
4. ![Diagram 4]

(b) The positive charge is now moved and kept off-center inside the fixed spherical neutral conducting shell. Which of the following represents the charge distribution on the inner and outer surfaces of the shell?

1. ![Diagram 1]
2. ![Diagram 2]
3. ![Diagram 3]
4. ![Diagram 4]
5. ![Diagram 5]

(c) The positive charge +Q is now kept fixed at the center of a spherical neutral conducting shell. An object with negative charge −Q is brought near the outside of the sphere. Which of the following represents the charge distributions?

1. ![Diagram 1]
2. ![Diagram 2]
3. ![Diagram 3]
4. ![Diagram 4]
(a) The red arrows indicate electric field lines. What net charge is inside the yellow box?

1. Positive
2. Negative
3. Zero
4. Cannot be determined

(b) All sides of the blue box are 2m X 2m, and the normal to the front side of the box is shown by the black arrow. A uniform 10 N/C electric field is incident into the front surface at an angle of 30 degrees, as shown by the red arrow. What is the flux through the front surface?

1. 20 N-m^2/C
2. -20 N-m^2/C
3. 35 N-m^2/C
4. -35 N-m^2/C
5. 40 N-m^2/C
6. -40 N-m^2/C

(c) A solid neutral cube one meter on each side is oriented with sides perpendicular to x, y, and z axes. This cube resides inside a uniform electric field \( \vec{E} = 50 \text{N/C} \). What is the net flux through the cube?

1. 100 N-m^2/C
2. 50 N-m^2/C
3. 0 N-m^2/C
4. -50 N-m^2/C
5. -150 N-m^2/C

Figure B.12: E & M Clicker Question Sequence B12
Continued

Figure B.13: E & M Clicker Question Sequence B13

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A ball with charge $-50e$ lies off-center inside a hollow spherical metal shell that has a net charge of $-100e$. What are the charges on the shell's inner surface and outer surface, respectively?

1. Inner $-50e$, outer $-50e$
2. Inner $0e$, outer $-100e$
3. Inner $+50e$, outer $-100e$
4. Inner $+50e$, outer $-150e$
5. Inner $0e$, outer $-50e$
6. Inner $+50e$, outer $-50e$
7. Cannot be determined
One large conducting plate carries a uniform charge density $\eta$. What is the electric field on each side of the plate if we define the direction to the right to be positive?

![Diagram](Image)

<table>
<thead>
<tr>
<th>Region A</th>
<th>Region C</th>
</tr>
</thead>
<tbody>
<tr>
<td>$-\eta/2\epsilon_0$</td>
<td>0</td>
</tr>
<tr>
<td>$-\eta/2\epsilon_0$</td>
<td>$+\eta/2\epsilon_0$</td>
</tr>
<tr>
<td>$+\eta/2\epsilon_0$</td>
<td>$+\eta/2\epsilon_0$</td>
</tr>
<tr>
<td>0</td>
<td>$+\eta/2\epsilon_0$</td>
</tr>
<tr>
<td>None of the above</td>
<td></td>
</tr>
</tbody>
</table>

Two large parallel conducting plates are kept a short distance apart. One plate carries a uniform charge density $\eta$ and the other a uniform charge density $-\eta$. What are the electric fields in the three regions if we define the direction to the right as positive?

![Diagram](Image)

<table>
<thead>
<tr>
<th>Region A</th>
<th>Region B</th>
<th>Region C</th>
</tr>
</thead>
<tbody>
<tr>
<td>$-\eta/2\epsilon_0$</td>
<td>$\eta/2\epsilon_0$</td>
<td>$\eta/2\epsilon_0$</td>
</tr>
<tr>
<td>$-\eta/\epsilon_0$</td>
<td>$\eta/2\epsilon_0$</td>
<td>$\eta/\epsilon_0$</td>
</tr>
<tr>
<td>0</td>
<td>$\eta/2\epsilon_0$</td>
<td>0</td>
</tr>
<tr>
<td>$-\eta/2\epsilon_0$</td>
<td>$\eta/\epsilon_0$</td>
<td>$\eta/2\epsilon_0$</td>
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<tr>
<td>$-\eta/\epsilon_0$</td>
<td>$\eta/\epsilon_0$</td>
<td>$\eta/\epsilon_0$</td>
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<tr>
<td>0</td>
<td>$\eta/\epsilon_0$</td>
<td>0</td>
</tr>
<tr>
<td>$-\eta/2\epsilon_0$</td>
<td>0</td>
<td>$\eta/2\epsilon_0$</td>
</tr>
<tr>
<td>$-\eta/\epsilon_0$</td>
<td>0</td>
<td>$\eta/\epsilon_0$</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Two large parallel conducting plates are kept a short distance apart. Both plates carry a uniform charge density $+\eta$. What are the electric fields in the three regions if we define the direction to the right as positive?

![Diagram](Image)

<table>
<thead>
<tr>
<th>Region A</th>
<th>Region B</th>
<th>Region C</th>
</tr>
</thead>
<tbody>
<tr>
<td>$-\eta/2\epsilon_0$</td>
<td>$\eta/2\epsilon_0$</td>
<td>$\eta/2\epsilon_0$</td>
</tr>
<tr>
<td>$-\eta/\epsilon_0$</td>
<td>$\eta/2\epsilon_0$</td>
<td>$\eta/\epsilon_0$</td>
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<tr>
<td>0</td>
<td>$\eta/2\epsilon_0$</td>
<td>0</td>
</tr>
<tr>
<td>$-\eta/2\epsilon_0$</td>
<td>$\eta/\epsilon_0$</td>
<td>$\eta/2\epsilon_0$</td>
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<td>$-\eta/\epsilon_0$</td>
<td>$\eta/\epsilon_0$</td>
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<td>0</td>
<td>$\eta/\epsilon_0$</td>
<td>0</td>
</tr>
<tr>
<td>$-\eta/2\epsilon_0$</td>
<td>0</td>
<td>$\eta/2\epsilon_0$</td>
</tr>
<tr>
<td>$-\eta/\epsilon_0$</td>
<td>0</td>
<td>$\eta/\epsilon_0$</td>
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<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Rank in order, from largest to smallest, the current densities $J_a$ to $J_d$ in these four wires, which carry currents ranging from $I$ to $2I$. (Remember that the area is $\pi r^2$)

1. $J_b = J_d > J_a > J_c$
2. $J_b > J_a > J_c > J_d$
3. $J_c > J_b = J_d > J_a$
4. $J_c > J_d > J_a > J_b$
5. $J_c > J_b > J_d = J_a$

A wire carrying a current $I$ has two segments which have equal diameters. If the conductivities for the two segments have the ratio $\sigma_1:\sigma_2=2:1$, what is the ratio $E_1:E_2$ of the electric field strengths in the two segments of the wire.

1. $E_1:E_2=4:1$
2. $E_1:E_2=2:1$
3. $E_1:E_2=1:1$
4. $E_1:E_2=1:2$
5. $E_1:E_2=1:4$
6. None of the above

The ratio of the conductivities $\sigma_1:\sigma_2$ is 4:1, what should the ratio of the radii (not area) of these two wires be in order for the electric field strength to be the same in both wires?

1. $R_1:R_2=4:1$
2. $R_1:R_2=2:1$
3. $R_1:R_2=1:2$
4. $R_1:R_2=1:4$
5. $R_1:R_2=1:1$
6. None of the above
A positive charge moving at constant velocity enters a region with uniform electric field. Neglecting other forces, the charge always will

1. Keep moving with a constant velocity.
2. Speed up.
3. Slow down.
4. Move in a circle.
5. None of the above.

A negative charge, which is free to move, is released from rest in an electric field. Neglect non-electrical forces. It will always move to a position with:

1. higher potential.
2. lower potential.
3. Electric field with higher magnitude.
4. Electric field with lower magnitude.
5. Larger electrical force.

A charge is released from rest in an electric field. Neglect non-electrical forces. Independently of the sign of the charge, it will always move to a position:

1. With higher potential.
2. With lower potential.
3. Where it has higher potential energy.
4. Where it has lower potential energy.
5. Where the electric field has higher magnitude.
6. Where the electric field has lower magnitude.
Figure B.16 continued

(d) A proton is placed at position P on the x axis where the potential is -10V. Which of the following statements is true?

1. The proton will move to the -x direction.
2. The proton will move to the +x direction.
3. The proton will not move at all.
4. The motion can not be predicted.
A proton is released from rest at point B, where the potential is 0 V. Afterward, the proton
1. moves toward A with an increasing speed.
2. moves toward A with a steady speed.
3. remains at rest at B.
4. moves toward C with a steady speed.
5. moves toward C with an increasing speed.

An electron initially at point D is moved to C. The electron is at rest before and after the move. How much work is done on the electron by the outside force (which is opposite to the electric force) during the move?
1. 0 eV
2. 200 eV
3. 100 eV
4. 50 eV
5. -100 eV
6. -200 eV

Which set of equipotential surfaces (shown below) is the best qualitative match to the electric field shown above?

Figure B.17: E & M Clicker Question Sequence B17
The dotted lines represent equipotential lines of given potential as shown below. Which set of arrows best describes the relative magnitudes and directions of the electrical fields at points A and B?

50 V  0 V  10  20  30  40  50V

1. A → B
2. A → B
3. A → B
4. A → B
5. A → B
6. A → B
7. A → B
8. None of the above.
A negative test charge \( Q = -0.6 \text{C} \) was moved from point A to point B in a uniform electric field \( E=5 \text{N/C} \). The test charge is at rest before and after the move. The distance between A and B is 0.5m and the line connecting A and B is perpendicular to the electric field. How much work was done by the net external force while moving the test charge from A to B?

![Diagram](image)

1. 1.5J
2. 0J
3. -1.5J
4. 3.0J
5. -3.0J

After moving the -0.6C test charge from A to B, it was then moved from B to C along the electric field line. The test charge is at rest before and after the move. The distance between B and C also is 0.5m. How much work was done by the net external force while moving the test charge from A to C?

![Diagram](image)

1. 1.5J
2. 0J
3. -1.5J
4. 2.12J
5. -2.12J
6. 3.0J
7. -3.0J

Instead of moving the test charge from A to B then to C, it is moved from A to D and then back to C. The test charge is at rest before and after the move. How much work was done by the net external force while moving the test charge this time?

![Diagram](image)

1. 1.5J
2. 0J
3. -1.5J
4. Infinitely big
5. Do not know at this time.
+1.5 J of work was done by the net external force while moving the -0.6 C test charge from B to C. The test charge is at rest before and after the move. What is the voltage difference between B and C, and at which point is the voltage larger?

1. 2.5 V, voltage higher at B.
2. 2.5 V, voltage higher at C.
3. 0.9 V, voltage higher at B.
4. 0.9 V, voltage higher at C.
5. 1.5 V, voltage higher at B.
6. 1.5 V, voltage higher at C.
(a) The distance between two parallel plates is increased while they remain hooked to a battery. The energy stored in the capacitor will:

1. Decrease
2. Increase
3. Remain the same
4. There’s not enough information to say.

(b) The distance between two parallel plates is doubled while they remain hooked to a battery. The battery voltage also is doubled. The energy stored in the capacitor will:

1. Decrease
2. Increase
3. Remain the same
4. There’s not enough information to say.

(c) Two parallel plates are charged to +Q and –Q using a battery, and then the battery is removed. Subsequently, the distance between these isolated plates is increased as shown. The capacitor’s stored energy will:

1. Decrease
2. Increase
3. Remain the same
4. There’s not enough information to say.

Figure B.19: E & M Clicker Question Sequence B19
Figure B.20: E & M Clicker Question Sequence B20
V again is 10 volts, and C₁, C₂ and C₃ are 1, 2 and 3 microfarads, respectively. The voltage is least on which capacitor? (Remember \( V = Q/C \))

1. C₁
2. C₂
3. C₃
4. C₂ and C₃
Continued

Figure B.21: E & M Clicker Question Sequence B21
Calculate the equivalent capacitance between A and B. It is almost the same sketch as before, but we’ve added a horizontal connection.

1. \( \frac{C}{2} \)
2. \( C \)
3. \( \frac{4C}{3} \)
4. \( \frac{3C}{2} \)
5. \( 6C \)
Continued

Figure B.22: E & M Clicker Question Sequence B22
Figure B.22 continued

(d) V is 10 volts, C₁, C₂, and C₃ are all 2 microfarads. The switch is first at position 1, then is switched to 2. The final charge on C₁ is:

1. 5 µC
2. 10 µC
3. 6.67 µC
4. 13.33 µC
5. 0 µC
Calculate the electric field due to two +q point charges at the point P midway between them.

\[ \frac{kq}{d^2} \text{ to the right.} \]

1. \( \frac{2kq}{d^2} \text{ to the right.} \)
2. Zero.
3. \( \frac{2kq}{d^2} \text{ to the left.} \)
4. \( \frac{kq}{d^2} \text{ to the right.} \)
5. \( \frac{kq}{d^2} \text{ to the left.} \)

Calculate the potential due to two +q point charges at the point P midway between them.

\[ \frac{2kq}{d} \]

1. \( \frac{2kq}{d} \text{ to the right.} \)
2. \( \frac{2kq}{d} \text{ to the right.} \)
4. \( \frac{kq}{d} \)
5. \( \frac{kq}{d} \text{ to the left.} \)

Now, the right-hand point charge is changed to \(-q\). Calculate the electric field and potential at the point P midway between the two point charges.

\[ \frac{2kq}{d^2} \text{ to right.} \]

1. \( \frac{2kq}{d^2} \text{ to right.} \)
2. \( \frac{2kq}{d^2} \text{ to right.} \)
3. \( 0 \)
4. \( 0 \)
5. \( \frac{2kq}{d^2} \text{ to left.} \)
6. \( \frac{2kq}{d^2} \text{ to left.} \)

<table>
<thead>
<tr>
<th>Electric Field</th>
<th>Potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>2kq/d to right.</td>
<td>2 kq/d</td>
</tr>
<tr>
<td>2kq/d to right.</td>
<td>Zero</td>
</tr>
<tr>
<td>0</td>
<td>2kq/d</td>
</tr>
<tr>
<td>0</td>
<td>-2kq/d</td>
</tr>
<tr>
<td>2kq/d to left.</td>
<td>-2kq/d</td>
</tr>
<tr>
<td>2kq/d to left.</td>
<td>Zero</td>
</tr>
</tbody>
</table>

Figure B.23: E & M Clicker Question Sequence B23
Figure B.23 continued

(d) Calculate the electric field and potential at the center of a square with sides of length \( d \).

\[ \begin{array}{c|c|c}
\text{Electric Field} & \text{Potential} \\
1. \sqrt{2}kq/d^2 \text{ right} & 2\sqrt{2}kq/d \\
2. \sqrt{2}kq/d^2 \text{ left} & \text{Zero} \\
3. \text{Zero} & \text{Zero} \\
4. \text{Zero} & 2\sqrt{2}kq/d \\
5. 4kq/d^2 \text{ right} & 4kq/d \\
6. 4kq/d^2 \text{ left} & \text{Zero} \\
\end{array} \]
The distance between two parallel plates is increased \textit{while they remain hooked to a battery}. Which one of the following statement is true?

1. The voltage between the plates will decrease.
2. The electric field between the plates will increase.
3. The charge on the plates will decrease.
4. The capacitance of these two plates will increase.
5. None of the above.

Two parallel plates are charged to $+Q$ and $-Q$ using a battery, and then the battery is removed. Subsequently, the distance between these isolated plates is increased as shown. Which of the following statement is true?

1. The voltage between the plates will increase.
2. The electric field between the plates will decrease.
3. The capacitance between the plates will increase.
4. The charge on the plates will decrease.
5. None of the above.

Select the correct plots of $E$ and $V$ versus distance between two parallel plates of a capacitor: (The plates are 2 cm apart.)

1. 
2. 
3. 
4. 

Continued
Now place a neutral 1 cm conducting slab symmetrically between the plates, and again select the correct E and V versus x graphs:
(The plates are 2 cm apart.)

1. E
2. E
3. E
4. E

First charge the plates and then remove the battery. Finally, place a neutral 1 cm conducting slab symmetrically between the plates, and again draw E and V:
(The plates are 2 cm apart.)
Figure B.25: E & M Clicker Question Sequence B25
(a) 1) A ground is first connected on the right side of the uncharged silver conductor.
2) A positively charged blue insulator is then brought from far away up close to (but not touching) the conductor’s left side.
3) The insulator is then taken away and then the ground is disconnected from the conductor.

**Afterward, what is the net charge on the conductor?**

1. Positive charge.
2. Negative charge.
4. Cannot tell from the information given.

(b) 1) A ground is first connected to the right side of the uncharged silver conductor.
2) A positively charged blue insulator is then brought from far away up close to (but not touching) the conductor’s left side.
3) The ground is then disconnected and then the insulator is taken far away from the conductor.

**Afterward, what is the net charge on the conductor?**

1. Positive charge.
2. Negative charge.
4. Cannot tell from the information given.

(c) 1) A ground is first connected to left side of the uncharged silver conducting object.
2) A positively charged blue insulator is then brought from far away up close to (but not touching) the conductor’s left side.
3) The ground is then disconnected and then the insulator is again taken far away from the conductor.

**Afterward, what is the net charge on the conductor?**

1. Positive charge.
2. Negative charge.
4. Cannot tell from the information given.

Figure B.26: E & M Clicker Question Sequence B26
Which of these following graphs shows a capacitor charging to a higher voltage?

Which of the following graphs shows a capacitor discharging?

What is the time constant for the discharge of the capacitors in the following Figure?

- 1ms
- 1s
- 2ms
- 2s
- 4ms
- 8ms
- None of the above.

Figure B.27: E & M Clicker Question Sequence B27
What is the equivalent resistance between points a and b?

![Circuit Diagram](image)

1. 20Ω
2. 40Ω
3. 10Ω
4. 6.67Ω
5. 60Ω
6. None of the above

The following circuit is called a *voltage divider*. What value of R will make $V_{out} = V_{in}/10$?

![Circuit Diagram](image)

1. 1100Ω
2. 1000Ω
3. 900Ω
4. 500Ω
5. 100Ω
6. None of the above

The 10Ω resistor is dissipating 40W of power. How much power is the 5Ω resistor dissipating?

![Circuit Diagram](image)

1. 20W
2. 30W
3. 40W
4. 45W
5. 60W
6. None of the above

Figure B.28: E & M Clicker Question Sequence B28
(a) Two **identical** bulbs A and B are connected in series to a battery. Which bulb is brighter?

1. A is brighter than B
2. B is brighter than A
3. They're the same brightness
4. Can't tell from the information given.

(b) What happens to the brightness of A when the switch is closed and identical bulb B also is connected in parallel across the same battery? After the switch is closed, how do bulbs A and B compare in brightness?

1. A dims when the switch is closed, and afterward A=B.
2. A stays the same, afterward A>B.
3. A dims, afterward A<B.
4. A stays the same, afterward A=B.
5. A gets brighter, afterward A>B.

(c) Rank in order, from brightest to dimmest, the identical bulbs A to D.

1. A = B = C = D
2. A > B > C = D
3. A > C > B > D
4. A > C = D > B
5. C = D > B > A

Figure B.29: E & M Clicker Question Sequence B29
Rank in order, from brightest to dimmest, the identical bulbs A to D. It’s almost the same drawing, but bulb A is now attached to the negative side of the battery.

1. $A = B = C = D$
2. $A > B > C = D$
3. $A > C > B > D$
4. $A > C = D > B$
5. $C = D > B > A$
The value of resistances and batteries are given algebraically, and the current names and directions are already chosen. Using Kirchoff’s rules, which of the following is the correct \( i_{\text{IN}} = i_{\text{OUT}} \) equation for point b?

1. \( i_1 = i_2 + i_3 \)
2. \( i_1 - i_2 = i_3 \)
3. \( i_1 + i_2 = -i_3 \)
4. \( i_3 = i_1 + i_2 \)
5. None of the above

Which of the following equations gives the correct Kirchhoff loop rule starting at point b and proceeding clockwise through batteries \( \varepsilon_1 \) and \( \varepsilon_2 \) and back to b?

1. \( i_1 R_1 + \varepsilon_1 - \varepsilon_2 - i_2 R_2 = 0 \)
2. \( -i_1 R_1 - \varepsilon_1 + \varepsilon_2 + i_2 R_2 = 0 \)
3. \( i_1 R_1 + \varepsilon_1 - \varepsilon_2 + i_2 R_2 = 0 \)
4. \( i_1 R_1 - \varepsilon_1 + \varepsilon_2 + i_2 R_2 = 0 \)
5. \( -i_1 R_1 + \varepsilon_1 - \varepsilon_2 + i_2 R_2 = 0 \)

Which of the following equations gives the correct Kirchhoff loop rule starting at point b and proceeding counterclockwise through batteries \( \varepsilon_3 \) and \( \varepsilon_2 \) and back to b?

1. \( \varepsilon_3 - i_3 R_3 + \varepsilon_2 + i_2 R_2 = 0 \)
2. \( i_3 R_3 + \varepsilon_2 - \varepsilon_3 + i_1 R_2 = 0 \)
3. \( \varepsilon_3 + i_3 R_3 - \varepsilon_2 + i_1 R_2 = 0 \)
4. \( -\varepsilon_3 + i_3 R_3 - \varepsilon_2 + i_1 R_2 = 0 \)
5. None of the above
Since there are 3 unknown and 3 loop equations can be written for the following circuit, it isn’t necessary to use a “current rules” equation.

1. Always true
2. Sometimes true
3. Always false
Which of these diagrams represent the same circuit?

1. a and b
2. a and c
3. a and d
4. b and c
5. a, b, and c
6. a, b, and d

What is the equivalent resistance of this circuit?

1. 5\,\Omega
2. 7\,\Omega
3. 8\,\Omega
4. 6.2\,\Omega
5. None of the above

What is the equivalent resistance between points a and b?

1. 7\,\Omega
2. 6.67\,\Omega
3. 17\,\Omega
4. 13\,\Omega
5. 5\,\Omega
6. None of the above

Figure B.31: E & M Clicker Question Sequence B31
In the following figure all resistors have the same value R and the voltage of the battery is V. Find the total current flow through the battery. One way to do this is to trace each possible path from one side of the battery back to the other side.

1. V/R
2. V/2R
3. V/3R
4. 2V/R
5. 3V/R
6. None of the above

Now, you add one wire to the same circuit as shown. Though there is only one additional wire, there are more paths going from one side of the battery to the other. Find the total current flow through the battery at this time.

1. V/R
2. V/2R
3. V/3R
4. 2V/R
5. 3V/R
6. None of the above

Consider the circuit given below. Each resistor has the same value R and the battery’s voltage is V. Find the total current flow through the battery. The loop in the diagonal wire means that it loops over the other wire and is connected only on its ends.

1. V/R
2. V/2R
3. V/3R
4. 2V/R
5. 3V/R
6. None of the above

Figure B.32: E & M Clicker Question Sequence B32
An Amperian loop is drawn around two current carrying wires, as shown below. What is the value of $\mathbf{B} \cdot d\mathbf{s}$ moving CCW, viewed from above, around the loop? (Note that $i_1$ and $i_2$ don't have to be the same size)

1. $\mu_0 i_1$
2. $\mu_0 i_2$
3. $\mu_0(i_1 - i_2)$
4. $\mu_0(i_1 + i_2)$
5. Zero

An irregularly-shaped Amperian loop is drawn around a wire carrying a current $I$. The wire is inclined at an angle $\theta$ to the plane of the loop. What is the value of $\mathbf{B} \cdot d\mathbf{s}$ moving CCW, viewed from above, around the loop? (The plane of the loop is cross-hatched.)

1. $\mu_0 I$
2. $\mu_0 I \sin(\theta)$
3. $\mu_0 I \cos(\theta)$
4. $\mu_0 I \tan(\theta)$
5. $-\mu_0 I$
6. Zero

An Amperian loop is drawn around wires carrying current $I_1$ and $I_2$. The loop is irregular and folded over between the two currents, as shown by the arrows. The wires are inclined at angles $\theta_1$ and $\theta_2$ to the plane of the loop. What is the value of $\mathbf{B} \cdot d\mathbf{s}$ moving in the direction shown around the loop?

1. $\mu_0(I_2 - I_1 \cos \theta_1)$
2. $\mu_0(I_2 \cos \theta_2 + I_1)$
3. $\mu_0(I_2 \cos \theta_2 + I_1 \cos \theta_1)$
4. $\mu_0(I_2 \cos \theta_2 - I_1 \cos \theta_1)$
5. $\mu_0(I_1 + I_2)$
6. $\mu_0(I_2 - I_1)$

Figure B.33: E & M Clicker Question Sequence B33
Current is flowing to the right in a wire. The magnetic field at the position P points

What is the direction of the magnetic field inside the solenoid?

A current in the loop has created the magnetic field, B, shown below. What is the current direction in this loop if you look from the top? And which side of the loop is the north pole? (To get the pole, you need to replace the loop with a bar magnet that has the same field direction)

Figure B.34: E & M Clicker Question Sequence B34
What is the direction of the magnetic field at point P, which is exactly in the middle of two parallel wires carrying equal currents I in opposite directions?

1. Goes into the page
2. Goes out of the page
3. Goes left
4. Goes right
5. There is no magnetic field at point P.

What is the direction of the magnetic field at point P, which is at the center of a semicircular loop of wire carrying a current I as shown?

1. Goes into the page
2. Goes out of the page
3. Goes left
4. Goes right
5. There is no magnetic field at point P.

All of the current loops below carry the same current I. Rate them according to the strength of the magnetic field at the red dot, from largest to smallest.

1. A>B>C
2. A>C>B
3. B>C>A
4. B>A>C
5. C>B>A
6. C>A>B

Figure B.35: E & M Clicker Question Sequence B35
A permanent magnet has field lines as shown below. An electron moves out of the slide toward you at point A. The magnetic force on the electron is best represented by:

1.  
2.  
3.  
4.  
5. Zero  
6. None of the above

A proton moves to the right at point B. The magnetic force on the proton is best represented by:

1.  
2.  
3.  
4.  
5. Zero  
6. None of the above

An electron moves vertically upward (on this page) at point C. The magnetic force on the electron is best represented by:

1.  
2.  
3.  
4.  
5. Zero  
6. None of the above

Figure B.36: E & M Clicker Question Sequence B36

Continued
A proton is at rest at point D. The magnetic force on the proton is best represented by:

- A
- B
- C
- D
- Zero
- None of the above
A negative charge is placed at rest in a magnetic field as shown below. What is the direction of the magnetic force on the charge?

1. Left
2. Right
3. Up
4. Down
5. Into the page
6. Out of the page
7. No force at all.

A negatively charged particle is moving horizontally to the right in a uniform magnetic field that is pointing in the same direction as the velocity. What is the direction of the magnetic force on the charge?

1. Left
2. Right
3. Up
4. Down
5. Into the page
6. Out of the page
7. No force at all.

Now, another negatively charged particle is moving upward and to the right in a uniform magnetic field that points in the horizontal direction. What is the direction of the magnetic force on the charge?

1. Left
2. Right
3. Up
4. Down
5. Into the page
6. Out of the page
7. No force at all.
A permanent magnet has magnetic field lines as shown below. A wire oriented perpendicular to the slide carries a current toward you at point A. The magnetic force on the wire is best represented by:

1. 2. 3. 4. 5. Zero 6. None of the above

A wire carries a current to the right. The magnetic force on this wire at point B is best represented by:

1. 2. 3. 4. 5. Zero 6. None of the above

A wire carries a current vertically upward. The magnetic force on this wire at point C is best represented by:

1. 2. 3. 4. 5. Zero 6. None of the above

Figure B.38: E & M Clicker Question Sequence B38
(a) An electron enters a magnetic field directed into the page, as shown below. It will experience

1. A force directed along its motion
2. A force directed opposite to its motion
3. A force directed upward on the page
4. A force directed downward on the page
5. No force for this direction of B field.

(b) An airplane viewed from above flies through a small magnetic field oriented vertically downward toward the ground (into the page), as shown below. Which of the following statements is true?

1. The plane’s front (F) becomes positively charged.
2. The tip of the left wing (L) becomes positively charged.
3. The tip of the right wing (R) becomes positively charged.
4. The top of the plane becomes positively charged.
5. None of the above, there’s no charging mechanism.

(c) A thin slab of Germanium is used as a Hall Effect probe. How would you orient a magnetic field to make the side facing out of the page be at a positive voltage with respect to the opposite side facing into the page? (In this case, the current is composed of moving electrons, not positive charges)

1. Into the page
2. Out of the page
3. Pointing right on the page
4. Pointing left on the page.
5. Downward on the page
6. Upward on the page.

Figure B.39: E & M Clicker Question Sequence B39
You have two parallel wires carrying currents in the same direction. What is the direction of the magnetic field at the position where \( I_2 \) located that is created by \( I_1 \)?

You have two parallel currents with the same direction. What is the direction of the magnetic force due to \( I_1 \) that acts on \( I_2 \)?

Figure B.40: E & M Clicker Question Sequence B40
A proton enters a uniform magnetic field into the page as shown. Which of the following could be its subsequent trajectory?


A proton enters a uniform magnetic field and follows trajectory B. A deuteron (same charge and twice the mass) enters the magnetic field in the same way and with the same velocity as the proton. Which of the following is the right trajectory for the deuteron?


A proton enters a magnetic field and follows trajectory B. An alpha particle (twice the charge and 4 times the mass) enters the same magnetic field in the same way and with the same velocity as the proton. Which of the following is the right trajectory for the alpha?


Figure B.41: E & M Clicker Question Sequence B41
Figure B.42: E & M Clicker Question Sequence B42
(a) Consider coil positions P, Q, R and S. A uniform magnetic field is confined to the region shown, and a loop moves to the right with a uniform speed. What happens to the magnitude of the flux through the loop between positions P and Q?

1. Increases
2. Stays the same
3. Decreases
4. Can not say for sure

(b) Consider coil positions P, Q, R and S. A uniform magnetic field is confined to the region shown, and a loop moves to the right with a uniform speed. What happens to the magnitude of the current in the loop between positions P and Q?

1. Increases
2. Stays the same
3. Decreases
4. Can not say for sure

(c) Consider coil positions P, Q, R and S. A uniform magnetic field is confined to the region shown, and the loop moves to the right. What happens to the magnitude of the flux through the loop between positions Q and R?

1. Increases
2. Stays the same
3. Decreases
4. Can not say for sure

Figure B.43: E & M Clicker Question Sequence B43
Which of the following graphs best represents the current in the loop as it moves at constant speed from position a to position d?
Figure B.44: E & M Clicker Question Sequence B44
The current through the top coil varies with time as shown on the right. Which description corresponds to the graph shown?

1. The current first decreases at a constant rate, then it stays constant, and finally increases at a constant rate.
2. The current first increases at a constant rate, then it stays constant, and finally decreases at a constant rate.
3. The current first stays constant, then it increases, and finally increases more.
4. The current first decreases, then it increases, and finally increases more.
5. None of the above.

The current through the top coil varies with time as shown on the right. Which of the following curves gives the correct current versus time in the secondary circuit on the right? Arrows show the direction of positive current in both coils.

Another pattern for current versus time is shown on the right. Which of the following qualitatively shows the ammeter reading current in the secondary. It is hooked up so that it reads positive current when its top side is more positive than its bottom side.

Figure B.45: E & M Clicker Question Sequence B45
(a) Is there an induced current in this circuit? If so, what is its direction?

![Diagram of a conducting metal rod with magnetic field](image)

1. Yes, clockwise.
2. Yes, counterclockwise.
3. No.

(b) A rectangular loop could move in three directions near a straight long wire with current $I$. In which direction can you move the rectangular loop so the loop has an induced current in the loop?

![Diagram of a rectangular loop and wire](image)

A. 1 only.
B. 1 and 2 only.
C. 2 only.
D. 1 and 3 only.
E. 2 and 3 only.
F. 1, 2, and 3.
G. None of the above.

(c) A conducting loop is halfway into a magnetic field. Suppose the magnitude of the magnetic field begins to increase rapidly in strength. What happens to the loop?

![Diagram of a magnetic field and loop](image)

1. The loop is pushed upward, toward the top of the page.
2. The loop is pushed downward, toward the bottom of the page.
3. The loop is pulled to the left, into the magnetic field.
4. The loop is pushed to the right, out of the magnetic field.
5. The tension in the wires increases, but the loop doesn't move.

Figure B.46: E & M Clicker Question Sequence B46
You move the north end of a magnet toward a loop as shown. What will be the direction of the induced current viewed from the meter side?

1. Clockwise
2. Counter Clockwise
3. No current

Immediately after you close the switch, what will be the direction of the induced current, again viewed from the meter side?

1. Clockwise
2. Counter Clockwise
3. No current

Initially, the magnet and the loop are not moving. Then, the loop starts to rotate around its center (denoted by the dotted line). The rotation is clockwise when viewed from the magnet side. What will be the direction of the induced current in the loop when viewed from the magnet side?

1. Clockwise
2. Counter Clockwise
3. No current
The figure shows two wire loops, with edge lengths of L and 2L, respectively. Both loops will move through a region of uniform magnetic field $B$ at the same constant velocity. Rank them according to the EMF induced just as their front edges enter the $B$ field region.

1. $a > b$
2. $a = b$
3. $a < b$
4. Depends on the magnitude of their common velocity
5. Depends on the magnitude of the $B$ field.

The figure shows four wire loops, with edge lengths of either L or 2L. All four loops will move through a region of uniform magnetic field $B$ at the same constant velocity. Rank them according to the EMF induced just as they enter the $B$ field region.

1. $a < b < d < c$
2. $a < b = d < c$
3. $a < b < c < d$
4. $a = b < c = d$
5. $a = b < d < c$

A circular wire loop moving at constant velocity enters a long region of uniform magnetic field $B$. Which one of the graphs describes the emf $\varepsilon$ in the loop as a function of time $t$?

1. $\varepsilon_t$
2. $\varepsilon_t$
3. $\varepsilon_t$
4. $\varepsilon_t$
5. $\varepsilon_t$

Figure B.48: E & M Clicker Question Sequence B48
An ideal transformer is shown below. The voltage on the primary circuit is 10V. The primary circuit has 4 turns, the secondary circuit has 8 turns. What is the voltage on the secondary circuit.

1. 5V
2. 2.5V
3. 10V
4. 20V
5. 40V

An ideal transformer is shown below. The current in the primary circuit is 10mA. The primary circuit has 4 turns, the secondary circuit has 8 turns. What is the current in the secondary circuit.

1. 5mA
2. 2.5mA
3. 10mA
4. 20mA
5. 40mA

An ideal transformer (no power loss) is shown below. The primary circuit has 4 turns, the secondary circuit has 8 turns. What is the ratio of the power dissipated in the primary circuit and the power dissipated in the secondary circuit?

1. 1:1
2. 1:2
3. 2:1
4. 1:4
5. 4:1

Figure B.49: E & M Clicker Question Sequence B49
APPENDIX C
CLICKER QUESTION SEQUENCES
FOR
WAVES, OPTICS, & MODERN PHYSICS
An object undergoes a simple harmonic motion on a smooth table. If the \textbf{amplitude} is \textbf{doubled}, the maximum force on the object is:

1. Quartered
2. Halved
3. Quadrupled
4. Doubled
5. Unchanged

An object moves with simple harmonic motion on a smooth table. If the \textbf{amplitude} and the \textbf{period} are both \textbf{doubled}, the object’s maximum \textbf{speed} is:

1. quartered.
2. halved.
3. quadrupled.
4. doubled.
5. unchanged.

An object moves with simple harmonic motion on a smooth table. If the \textbf{amplitude} and the \textbf{period} are both \textbf{doubled}, the object’s maximum \textbf{acceleration} is:

1. quartered.
2. halved.
3. quadrupled.
4. doubled.
5. unchanged.

Figure C.1: Waves, Optics, & Modern Physics Clicker Question Sequence C1
Figure C.2: Waves, Optics, & Modern Physics Clicker Question Sequence C2
At \( t=0 \), an oscillator is started with zero velocity at its maximum positive amplitude \( x_m \). The equation for simple harmonic motion is:

\[
x(t) = x_m \cos(\omega t + \phi)
\]

What is the value of \( \phi \)?

1. 0
2. \(+\pi/4\)
3. \(-\pi/4\)
4. \(+\pi/2\)
5. \(-\pi/2\)
6. None of the above.

At \( t=0 \), an oscillator is started with maximum negative velocity at \( x(0)=0 \). The equation for simple harmonic motion is:

\[
x(t) = x_m \cos(\omega t + \phi)
\]

What is the value of \( \phi \)?

1. 0
2. \(+\pi/4\)
3. \(-\pi/4\)
4. \(+\pi/2\)
5. \(-\pi/2\)
6. None of the above.

The figure shows four oscillators at \( t = 0 \). Which one has the phase constant \( \phi_0 = +\left(\frac{\pi}{4}\right) \)?

---

Figure C.3: Waves, Optics, & Modern Physics Clicker Question Sequence C3
The figure shows four oscillators at \( t = 0 \). Which one has the phase constant \( \phi_0 = -\frac{\pi}{4} \)?
Figure C.4: Waves, Optics, & Modern Physics Clicker Question Sequence C4
Figure C.4 continued

The dotted blue curve shows the displacement vs. time of a simple harmonic oscillator. Which of the red curves shown below can be obtained by changing the phase without changing the amplitude and the angular frequency of the motion?

1. Graph 1 & 2
2. Graph 1 & 3
3. Graph 1 & 4
4. Graph 2 & 3
5. Graph 2 & 4
6. Graph 3 & 4
7. All of these
The graph below shows plots of the kinetic energy $K$ versus position $x$ for three harmonic oscillators with the same mass. Rank the plots according to the corresponding total energy of the oscillators.

(a)  
1. $A > B > C$
2. $A < B < C$
3. $A = B = C$
4. $B > A = C$
5. $B < A = C$
6. Can’t tell from the info given.

The graph below shows plots of the kinetic energy $K$ versus position $x$ for three harmonic oscillators with the same mass. Rank the plots according to the corresponding frequency of the oscillator.

(b)  
1. $A > B > C$
2. $A < B < C$
3. $A = B = C$
4. $B > A = C$
5. $B < A = C$
6. Can’t tell from the info given.

The graph below shows a plot of the kinetic energy $K$ versus position $x$ for a spring harmonic oscillator with a 1 kg mass. The maximum kinetic energy is 32 J. What is the angular frequency of this harmonic oscillator?

(c)  
1. 32 rad/s
2. 8 rad/s
3. 4 rad/s
4. 2 rad/s
5. 1 rad/s
6. Can’t tell from the info given.
Figure C.6: Waves, Optics, & Modern Physics Clicker Question Sequence C6

(a) Which of the response curves would you want for the sound-board on a piano?

Which of the following response curves would you want for the springs of your car?

Which of the response curves is closest to that of a tuning fork?

Continued
Which of the response curves would you want for the sound-board on a piano?

1. A
2. B
3. C
4. None of the above
The following is a snapshot at $t=0$ for a transverse wave traveling \textit{to the right} with velocity 2 m/s. Which of the following equations is correct for this wave?

1. $y(x,t) = 2 \sin \left( \frac{\pi}{2} x - (\pi) t \right)$
2. $y(x,t) = 2 \sin \left( \frac{\pi}{2} x - \frac{\pi}{2} t \right)$
3. $y(x,t) = 2 \sin \left( \frac{\pi}{2} x + \frac{\pi}{2} t \right)$
4. $y(x,t) = 2 \sin \left[ (\pi) x - (\pi) t \right]$
5. None of the above.

The following is a history at $x=0$ meter of a transverse wave traveling \textit{to the left} with velocity 2m/s. Which of the following equations is correct for this wave?

1. $y(x,t) = 2 \sin \left( \frac{\pi}{2} x + \frac{\pi}{2} t \right)$
2. $y(x,t) = 2 \sin \left( \frac{\pi}{2} x + (\pi) t \right)$
3. $y(x,t) = 2 \sin \left( \frac{\pi}{2} x + \frac{\pi}{2} t \right)$
4. $y(x,t) = 2 \sin \left[ (\pi) x + (\pi) t \right]$
5. None of the above.

The following is a history at $x=1$ meter of a transverse wave traveling \textit{to the right} with velocity 2m/s. Which of the following equations is correct for this wave?

1. $y(x,t) = 2 \sin \left[ \frac{\pi}{2} x - (\pi) t + \pi \right]$
2. $y(x,t) = 2 \sin \left[ \frac{\pi}{2} x - \frac{\pi}{2} t + \frac{\pi}{2} \right]$
3. $y(x,t) = 2 \sin \left[ \frac{\pi}{2} x - (\pi) t - \pi \right]$
4. $y(x,t) = 2 \sin \left[ \frac{\pi}{2} x - \frac{\pi}{2} t - \frac{\pi}{2} \right]$
5. $y(x,t) = 2 \sin \left[ \frac{\pi}{2} x - \frac{\pi}{2} t + \frac{\pi}{2} \right]$
6. Both 2 and 3.

Figure C.7: Waves, Optics, & Modern Physics Clicker Question Sequence C7
Figure C8: Waves, Optics, & Modern Physics Clicker Question Sequence C8
Two strings with different unit mass are tied in the center and attached with a tension of 1000N to two walls, as shown. What is the ratio of the wave’s speed in the two strings?

The wave speed in a wire is \( v = \sqrt{\frac{T}{\mu}} \)

1. \( \frac{v_1}{v_2} = \frac{9}{25} \)
2. \( \frac{v_1}{v_2} = \frac{3}{5} \)
3. \( \frac{v_1}{v_2} = \frac{5}{3} \)
4. \( \frac{v_1}{v_2} = \frac{25}{9} \)
5. \( \frac{v_1}{v_2} = 1 \)

Two strings with different unit mass are tied in the center and attached with a tension of 1000N to two walls, as shown. What is the ratio of the wave’s frequencies in the two strings?

1. \( \frac{f_1}{f_2} = \frac{9}{25} \)
2. \( \frac{f_1}{f_2} = \frac{3}{5} \)
3. \( \frac{f_1}{f_2} = \frac{5}{3} \)
4. \( \frac{f_1}{f_2} = \frac{25}{9} \)
5. \( \frac{f_1}{f_2} = 1 \)

Two strings with different unit mass are tied together as shown. What will the waves look like in the two strings?

- Choice One
- Choice Two
- Choice Three
- Choice Four

Figure C9: Waves, Optics, & Modern Physics Clicker Question Sequence C9
A satellite radio station puts out 10 kW of cool jazz for an hour at 99.3 MHz on your radio dial. How much energy per unit time goes through a sphere 50 kilometers in radius that is centered on the satellite. The drawing below is not to scale.

1. \( \frac{10 \text{ kW}}{(25 \text{ km})^2} \)
2. 10 kW
3. \( (10 \text{ kW}) \cdot (4\pi)(25 \text{ km})^2 \)
4. \( (10 \text{ kW}) \cdot (4\pi)(25 \text{ km})^2 \cdot (\text{time}) \)
5. None of the above

Now, the sphere enclosing the satellite that is broadcasting at 10 kW for an hour is way off center, as shown. The total power going through the sphere is now:

1. \( \frac{10 \text{ kW}}{(25 \text{ km})^2} \)
2. 10 kW
3. \( (10 \text{ kW}) \cdot (4\pi)(25 \text{ km})^2 \)
4. \( (10 \text{ kW}) \cdot (4\pi)(25 \text{ km})^2 \cdot (1 \text{ hour}) \)
5. None of the above

A ground-based radio station puts out 50 kW, and your radio needs to receive at least \( 1 \times 10^{-6} \text{ W/m}^2 \) of power per unit area in order to faithfully reproduce the sound of cool jazz. What is the maximum distance that you can be from the broadcast antenna?

1. 1000 km
2. 630 km
3. 316 km
4. 0
5. 32 km
6. 63 km

Figure C10: Waves, Optics, & Modern Physics Clicker Question Sequence C10
A speaker broadcasting at a frequency of 2 MHz is moving with a velocity of 200 m/s toward a stationary detector. What is the frequency that the detector will hear? The speed of sound is 343 m/s and the Doppler formula is:

\[ f' = f \left( \frac{v \pm v_{\text{detector}}}{v \pm v_{\text{source}}} \right) \]

1. 0.83 MHz
2. 4.8 MHz
3. 3.2 MHz
4. 1.3 MHz
5. 2 MHz

A detector is moving 200 m/s toward a stationary speaker broadcasting at a frequency of 2 MHz. What frequency will the detector hear? The speed of sound is 343 m/s and the Doppler formula is:

\[ f' = f \left( \frac{v \pm v_{\text{detector}}}{v \pm v_{\text{source}}} \right) \]

1. 0.83 MHz
2. 4.8 MHz
3. 3.2 MHz
4. 1.3 MHz
5. 2 MHz

A speaker is moving with a velocity of 200 m/s toward a detector, and the detector is moving with a velocity of 100 m/s away from the speaker. The speaker’s frequency is 2 MHz, what is the frequency that the detector will hear? (The speed of sound is 343 m/s, and all speeds are relative to the ground.)

**Method 1:** According to the detector, the speaker is approaching at 200-100=100 m/s, so the frequency is

\[ 2 \times \frac{100}{1+100/343} = 2.82 \text{ MHz} \]

**Method 2:** the speaker is moving 200 m/s towards the detector, and the detector is moving 100 m/s away. So the frequency is

\[ 2 \times \frac{100/343}{1-200/343} = 3.40 \text{ MHz} \]

1. Both methods are right
2. Both methods are wrong.
3. Only method 1 is right.
4. Only method 2 is right.
A **combined** speaker and detector system is moving at 100 m/s toward a wall. The speaker’s frequency is 2 MHz and the detector will hear the wave **reflected** by the wall. What frequency will the detector hear? The speed of sound is 343 m/s and the doppler formula is:

\[ f' = f \left( \frac{v \pm v_{\text{detector}}}{v \pm v_{\text{source}}} \right) \]

1. 2.82 MHz
2. 2.58 MHz
3. 3.65 MHz
4. 1.10 MHz
5. 2.00 MHz
(a) A pipe with two open ends is shown below. The length of the pipe is 1m and the speed of sound is 343m/s. What is the first harmonic frequency of the sound wave created in this pipe?

1. 343Hz
2. 172Hz
3. 686Hz
4. 1029Hz
5. None of the above

(b) A pipe with two close ends is shown below. The length of the pipe is 1m and the speed of sound is 343m/s. What is the first harmonic frequency of the sound wave created in this pipe?

1. 343Hz
2. 172Hz
3. 686Hz
4. 1029Hz
5. None of the above

(c) A pipe with one closed end is shown below. 428.75 Hz, 600.25 Hz and 771.75 Hz are three adjacent harmonic frequencies of sound waves created in this pipe. What is the pipe’s first harmonic (lowest) frequency?

1. 86Hz
2. 172Hz
3. 343Hz
4. 257Hz
5. None of the above
Two point sources, P and Q, emit sound waves of equal wavelengths ($\lambda$) and amplitudes (A). If you want to have fully constructive interference at point R, what has to be the phase difference between P and Q?

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1. 0
2. $1/(2\pi)$
3. 0.5
4. $1/\pi$
5. 1
6. $\pi$
7. None of the above

---

Two point sources, P and Q, emit sound waves of equal wavelengths ($\lambda$) and amplitudes (A). If you want to have fully destructive interference at point R, what has to be the phase difference between P and Q?

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1. 0
2. $1/(2\pi)$
3. 0.5
4. $1/\pi$
5. 1
6. $\pi$
7. None of the above

---

Two point sources, P and Q, emit sound waves of equal wavelengths ($\lambda$) and amplitudes (A). This time, the point source Q is moved closer to P as shown below. If you want to have fully destructive interference at point R, what has to be the phase difference between P and Q? (The distance between P & Q is $\lambda/2$; the distance between Q & R is $3\lambda/2$.)

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1. 0
2. $1/(2\pi)$
3. 0.5
4. $1/\pi$
5. 1
6. $\pi$
7. None of the above

---

Figure C.13: Waves, Optics, & Modern Physics Clicker Question Sequence C13
A fish swims below the surface of the water at P. Where should a fisherman throw a spear in order to catch it?

1. Toward where he sees the fish.
2. Above where he sees the fish.
3. Below where he sees the fish.

A fish swims below the surface of the water at P. Now the fisherman decides to point a laser beam that hits the fish. What should he do?

1. Point toward where he sees the fish
2. Point above where he sees the fish
3. Point below where he sees the fish

The fisherman stands above the water. A fish at P sees the fisherman’s eye at

1. Exactly where it really is.
2. Above where it really is.
3. Below where it really is.
Will the bulb connected to conducting wires glow? (The wires plus bulb system is aligned with the x-axis.)

1. Yes
2. No

Will the bulb connected to conducting wires glow? (The wires plus bulb system is aligned with the y-axis.)

1. Yes
2. No

Will the bulb connected to conducting wires glow? (The wires & bulb system is aligned with the z-axis.)

1. Yes
2. No

Figure C.15: Waves, Optics, & Modern Physics Clicker Question Sequence C15
The mirror in the following figure deflects a horizontal laser beam by 60°. What is the angle Φ?

1. 20°
2. 30°
3. 40°
4. 45°

A laser beam is incident on the left mirror in the following figure. If you want the reflected beam to always be parallel to the incident beam no matter which angle the incident beam goes in, what should the angle θ be?

1. 45°
2. 60°
3. 90°
4. 120°

Now if θ is 80°, what is the angle Φ of the reflected laser beam?

1. 15°
2. 30°
3. 45°
4. 20°
Your lecturer just drew the *incorrect* "refraction of light" sketch for light incident from air onto a blue glass plate, as shown below. What would you suggest to make it right?

1. Make $\theta_2$ smaller.
2. State that as drawn, $n_2 < n_1$.
3. Curve the ray in the lower medium.
4. Figure all angles from the perpendicular dotted line.
5. None of the above.

The light exits the same glass plate shown in the previous sketch. Select the direction that it will go when it exits the glass.

1. A
2. B
3. C
4. D
5. E

Several of your friends miss retrieving a gold happy face from the bottom of a stream on their first attempt. You dazzle everyone by drawing light rays illustrating that they were reaching in the wrong place. Which of the following sketches might you have drawn?

1. A
2. B
3. C

Figure C.17: Waves, Optics, & Modern Physics Clicker Question Sequence C17
A lens has been hidden behind a blue curtain, but you’ve been given three light (red) rays used to construct an image. Your task is to determine the type of lens and the type of image.

1. Convex (converging) lens, real image
2. Convex (converging) lens, virtual image
3. Concave (diverging) lens, real image
4. Concave (diverging) lens, virtual image

For the figure below, determine the lens and type of image.

1. Convex (converging) lens, real image
2. Convex (converging) lens, virtual image
3. Concave (diverging) lens, real image
4. Concave (diverging) lens, virtual image

For the figure below, determine the lens and type of image.

1. Convex (converging) lens, real image
2. Convex (converging) lens, virtual image
3. Concave (diverging) lens, real image
4. Concave (diverging) lens, virtual image
A symmetric pulse is approaching the right end of a string tied to two walls, as shown below on the right. Which of the following best represents the shape of the string after it has completely reflected off the wall on the right?

1.  
2.  
3.  
4. None of the above.

A symmetric pulse is approaching the right end of a string tied to two walls, as shown below on the right. At the precise moment when half of the wave has hit the wall, which of the following best represents the shape of the string?

1.  
2.  
3.  
4.  
5. None of the above.

Two identical pulses move in opposite directions toward opposite ends of a string tied to two walls, as shown on the right. Which of the following represents possible shape(s) for the string after both pulses have undergone reflections and meet somewhere in the middle.

1.  
2.  
3.  
4.  
5. 3 AND 4.  
6. None of the above.

Figure C.19: Waves, Optics, & Modern Physics Clicker Question Sequence C19
A lens is used to make an image; three light rays are drawn out of the infinite number coming from the arrowhead. The image given in this sketch could be seen:

1. By placing a screen at the image point.
2. Without a screen by looking back at the lens.
3. By both techniques (1) and (2).
4. Only if the lens is big enough.
5. None of the above answers is 100% correct.

A screen is placed at the position of the image, and a “sharp” image appears on the screen. Next, Jennifer moves the screen a SHORT distance TOWARD the lens. The image would appear:

1. Smaller and “sharper”.
2. Smaller and “fuzzier”.
3. Larger and “sharper”.
4. Larger and “fuzzier”.
5. Would disappear.

Finally, Jennifer blocks half the lens, as shown, with a piece of paper. What happens to the image?

1. It disappears.
2. Only half of it is still seen.
3. It looks the same, but gets slightly dimmer.
4. It gets fuzzy.
5. It depends on what part of the lens is blocked.

Figure C.20: Waves, Optics, & Modern Physics Clicker Question Sequence C20
Joe sees the image of a piece of paper containing a physics problem, as shown from above. Where does Joe see the image. (Joe would see the object as being at the image point if he didn’t know that the mirror existed.)

1. A
2. B
3. C
4. D
5. None of the above

Joe sees an image which is on a dotted line through the book and perpendicular to the mirror, as shown. Then, Joe moves sideways as shown by the brown arrow. Compared to its original location, the image that he sees

1. Doesn’t move
2. Is at the same distance from the mirror but above the dotted line
3. At the same distance but below the dotted line
4. On the dotted line but moves toward the mirror
5. On the dotted line but moves away from the mirror.

Figure C.21: Waves, Optics, & Modern Physics Clicker Question Sequence C21
A double-slit interference pattern is produced on a screen using monochromatic light of wavelength 600 nm. What will happen to the separation of the interference fringes ($\Delta y$) if you decrease the separation of the two slits $d$?

1. $\Delta y$ will increase
2. $\Delta y$ will decrease
3. $\Delta y$ will stay the same
4. Can’t be determined

A double-slit interference pattern is produced on a screen using monochromatic light of wavelength 600 nm. What will happen to the separation of the interference fringes ($\Delta y$) if you put a tank of kerosene between the double slits and the screen? ($n_{\text{kerosene}} > 1$)

1. $\Delta y$ will increase
2. $\Delta y$ will decrease
3. $\Delta y$ will stay the same
4. Can’t be determined

A double-slit interference pattern is produced on a screen using monochromatic light of wavelength 600 nm. What will happen to the separation of the interference fringes ($\Delta y$) if you decrease the distance between the slits and the screen $D$?

1. $\Delta y$ will increase
2. $\Delta y$ will decrease
3. $\Delta y$ will stay the same
4. Can’t be determined

Figure C.22: Waves, Optics, & Modern Physics Clicker Question Sequence C22
A double-slit interference pattern is produced on a screen using monochromatic light of wavelength 600 nm. What will happen to the separation of the interference fringes ($\Delta y$) if you instead use another monochromatic light of wavelength 632 nm?

1. $\Delta y$ will increase
2. $\Delta y$ will decrease
3. $\Delta y$ will stay the same
4. Can’t be determined
A diffraction grating has $N$ slits, and the intensities of the bright fringes are $I_0$. How will the peak intensities of the bright fringes change if you double number of the slits to $2N$? (The total width of the grating is kept fixed)

1. $2I_0$
2. $4I_0$
3. $\sqrt{2}I_0$
4. $\frac{1}{2}I_0$

A diffraction grating has $N$ slits, and the total energy deposited in the diffraction pattern is $E_0$. What will the energy deposited become if you double number of the slits to $2N$. (The width of the grating is kept fixed, and each slit can be viewed as a new source)

1. $2E_0$
2. $4E_0$
3. $\sqrt{2}E_0$
4. $\frac{1}{2}E_0$

In the original case with $N$ slits, the width of each bright fringe is $\Delta$. What will the width of bright fringe become if, as in the previous two questions, you double the number of slits without changing the overall width of the diffraction grating? (hint: Use conservation of energy)

1. $2\Delta$
2. $4\Delta$
3. $\sqrt{2}\Delta$
4. $\frac{1}{2}\Delta$

Figure C.23: Waves, Optics, & Modern Physics Clicker Question Sequence C23
Light of wavelength $\lambda$ falls almost perpendicularly on a thin film with index of refraction $n_2$ and thickness $t$. Below the thin film is an infinitely thick layer with index of refraction $n_3$. Which of the following equations would give destructive interference if $n_3 > n_2 > n_1$? ($\lambda_1$, $\lambda_2$, and $\lambda_3$ are the wavelengths of the light in the medium with index of refraction $n_1$, $n_2$, and $n_3$, respectively.)

1. $2t = 0$
2. $2t = \frac{1}{2}\lambda$
3. $2t = \lambda_1$
4. $2t = \frac{1}{2}\lambda_2$
5. $2t = \lambda_2$
6. Answers 1 and 2.

Light of wavelength 500nm falls almost perpendicularly on a thin film with index of refraction $n_2$. Below the film is an infinitely thick layer with index of refraction $n_3$. If $n_1 = 1$, $n_2 = 1.5$, and $n_3 = 1.3$, what is the minimum film thickness to get destructive interference?

1. 500 nm
2. $500 \text{ nm}/1.5$
3. $500 \text{ nm}/1.3$
4. $500 \text{ nm}/2$
5. $500 \text{ nm}/3$
6. $\sim 0$
7. No destructive interference can occur under this conditions.

Be careful! This time $n_2 > n_3$
In Young’s experiment, monochromatic light is used to produce an interference pattern on a screen. Now you put a thin sheet of glass (n = 1.5) behind the double slits, is the central location of the screen bright, dark or in between?

1. Bright  
2. Dark  
3. In between  
4. Depends on the thickness of the glass

In Young’s experiment, monochromatic light is used to produce an interference pattern on a screen. You put a thin sheet of glass (n = 1.5) behind the top slit. Now is the central location of the screen bright, dark or in between?

1. Bright  
2. Dark  
3. In between  
4. Depends on the thickness of the glass

In Young’s experiment, monochromatic light of wavelength 600 nm is used to produce an interference pattern on a screen. If you put a thin sheet of glass (n = 1.5) with thickness 0.012 mm behind the top slit, is the central location of the screen bright, dark or in between?

1. Bright  
2. Dark  
3. In between  
4. Can’t be determined

Figure C.25: Waves, Optics, & Modern Physics Clicker Question Sequence C4
A string is vibrating at 300 Hz. Using a strobe light and an ultra fast camera you get a picture of the string as sketched below. The blue walls are separated by 1 meter. If the string were vibrating in its lowest possible frequency, what would that frequency be?

1. 50 Hz
2. 100 Hz
3. 150 Hz
4. 200 Hz
5. 300 Hz
6. None of the above

A string is vibrating at 300 Hz. Using a strobe light and an ultra fast camera you get a picture of the string as sketched below. The blue walls are separated by 1 meter. What is the speed of the wave?

1. 50 m/s
2. 100 m/s
3. 150 m/s
4. 200 m/s
5. 300 m/s
6. None of the above

A string is vibrating at 300 Hz. Using a strobe light and an ultra fast camera you get a picture of the string as sketched below. The blue walls are separated by 1 meter. As determined in the previous question, the speed of the wave vibrating as shown is 200 m/s. What would its speed be if it were vibrating in the lowest possible frequency?

1. 50 m/s
2. 100 m/s
3. 150 m/s
4. 200 m/s
5. 300 m/s
6. None of the above.
The following shows a single-slit diffraction pattern, and P2 is a point at the second dark fringe. \( y_2 = 0.5 \text{ cm} \), \( a = 0.2 \text{ mm} \), and \( L = 4 \text{ m} \). What is the wavelength of this light?

1. 2000 nm (2 μm)
2. 1500 nm
3. 250 nm
4. 500 nm
5. 1000 nm

The following shows a double-slit interference pattern, and P is a point on the second dark fringe. The distance between the centers of the two slits is 0.4 mm, \( y = 12 \text{ mm} \) and \( L = 4 \text{ m} \). What is the wavelength of the incident light?

1. 800 nm
2. 480 nm
3. 1600 nm
4. 600 nm

A light wave travels through two equal-width slits. The distance between the centers of the slits is about nine times the width of each slit, so what will the intensity pattern look like?

A. B.
B. C.
C. D. None of the above

---

Figure C.27: Waves, Optics, & Modern Physics Clicker Question Sequence C27
(a) Which of the following pictures shows two headlights that cannot be resolved?

A  B  C  D

(b) Someone sitting on the opposite side of the football field puts his arm up in the air. Can you distinguish whether he is making the peace sign with his fingers or something else?

(Use 200 m for the distance between the person and you. Use 600 nm for the wavelength of light. Use 2.5 mm for the diameter of the pupil of the eye. Use 5 cm for the distance between fingers.)

1. Yes  
2. No

(c) Someone sitting on the opposite side of the football field puts his arm up in the air. Can you distinguish whether he is making the “I love you” sign with his fingers or something else? Ignore his thumb.

(Use 200 m for the distance between the person and you. Use 600 nm for the wavelength of light. Use 2.5 mm for the diameter of the pupil of the eye. Use 10 cm for the distance between fingers.)

1. Yes  
2. No
A single slit of width \( a \) is illuminated by light of wavelength \( \lambda \), so that the width of the central diffraction maxima is \( l \). Now you decrease the slit width to \( a/2 \). What is the width of the central diffraction maxima?

1. \( l/2 \)
2. \( 2l \)
3. \( l/4 \)
4. \( 4l \)
5. \( l \)

This time you keep the same slit width, but use another monochromatic light of wavelength 500 nm. How does the broadness of the central bright fringe change compared to that produced by the 600 nm wavelength?

1. Increases
2. Decreases
3. Stays the same
4. Depends on the exact value of the slit width

The slit opening is \( a=10 \, \mu m \) and the distance between the slit and the screen is \( L=3 \, m \). Calculate \( l \) for light of wavelength 500 nm.

1. 0.05 m
2. 0.10 m
3. 0.15 m
4. 0.20 m
5. 0.25 m
6. 0.30 m

Figure C.29: Waves, Optics, & Modern Physics Clicker Question Sequence C29
X rays with some wavelength are diffracted by crystal. The second diffraction maxima are observed at angle $\theta_B=60^\circ$, $d_B=2\text{nm}$. What is the wavelength of this x ray?

1. 2nm
2. 1nm
3. 3nm
4. 0.5nm

X rays with some wavelength are diffracted by a cubic crystal. The second diffraction maxima by surface $ABCD$ and $A_1B_1C_1D_1$ are observed at angle $60^\circ$. What is the second diffraction maxima angle by surface $A_1BD$ and $B_1CD_1$?

1. $45^\circ$
2. $32.5^\circ$
3. $27.5^\circ$
4. $30^\circ$
A mirror is behind a cloth and cannot be seen. Determine its type, whether the image is real or virtual, and the sign of the magnification $M$.

1. Concave mirror, real image, $M$ is positive
2. Concave mirror, real image, $M$ is negative
3. Concave mirror, virtual image, $M$ is positive
4. Concave mirror, virtual image, $M$ is negative
5. Convex mirror, virtual image, $M$ is positive
6. Convex mirror, virtual image, $M$ is negative

Figure C.31: Waves, Optics, & Modern Physics Clicker Question Sequence C31
Two polarizers are crossed at 90°. The first permits passage of horizontally polarized light, while the second permits passage of vertically polarized light. Unpolarized light with intensity $I_0$ is incident on the 1st polarizer. In terms of $I_0$, what is the intensity of the light between the two polarizers?

1. $I_0/2$
2. $I_0$
3. $2I_0$
4. $I_0\sqrt{2}$
5. Zero

Two polarizers are crossed at 90°. Unpolarized light with intensity $I_0$ is incident on the 1st polarizer. In terms of $I_0$, what is the intensity of the light after passing through both polarizers?

1. $I_0/2$
2. $I_0$
3. $2I_0$
4. $I_0\sqrt{2}$
5. Zero

Three polarizers are oriented at 0°, 60° and 90°. Unpolarized light wave with intensity $I_0$ is incident on the first polarizer. In terms of $I_0$, what is the intensity of the light after passing through the first two polarizers?

1. $(0.5)I_0$
2. $(0.25)I_0$
3. Zero
4. $(0.125)I_0$
5. $(0.094)I_0$
Three polarizers are oriented at 0°, 60°, and 90°. Unpolarized light wave with intensity $I_0$ is incident on the first polarizer. In terms of $I_0$, what is the intensity of the light after passing through all three polarizers?

1. $(0.5)I_0$
2. $(0.25)I_0$
3. Zero
4. $(0.125)I_0$
5. $(0.094)I_0$
Proper time is the time as measured in the rest frame of the clock. Which of the following statements is false?

1. The proper time interval is always shorter than the dilated time interval.
2. The proper time interval is the time interval (measured in an inertial reference frame) between two events occurring at the same location in that inertial reference frame.
3. The proper time interval depends on the relative speed between the observers in different inertial reference frames.
4. The proper time interval is measured by an observer who is at rest with respect to the events.

Which of the following statements is false?

1. The proper length is always larger than the contracted length.
2. The proper length is the measured distance between two points as measured by an observer at rest with respect to the two points.
3. The proper length depends on the relative speed between the observers in different inertial reference frames.
4. Dimensions perpendicular to the motion are not contracted.
5. Dimensions parallel to the motion are contracted.

Which of the following quantities will have the same measured value independent of the reference frame in which they were measured?

1. The speed of light in a vacuum
2. The time interval between two events
3. The length of an object
4. 1 & 2
5. 1 & 3
6. 2 & 3

Figure C.33: Waves, Optics, & Modern Physics Clicker Question Sequence C33
A spaceship is moving toward the Earth at a speed $v$ along the $x$ axis. A meter stick in the spaceship, which is originally parallel to the $x$ axis, is now rotated to be perpendicular to the $x$ axis. After correcting for time differences in transmission of light from different parts of the meter stick, what is the length $L$ for the meter stick calculated by the astronaut in the spaceship?

1. $L$ increases
2. $L$ decreases
3. $L$ doesn’t change
4. Depends on the exact value of $v$

A rigid stick in $S'$ frame makes an angle $\theta'$ of 45° with the $x'$ axis. The $S$ frame is moving parallel to the $x'$ axis at a speed $u$ relative to the $S'$ frame. After correcting for differences in transmission time for light coming from different parts of the meter stick, what angle $\theta$ with respect to the $x$ axis is calculated for the meter stick in the $S$ frame?

1. $\theta = 45^\circ$
2. $\theta < 45^\circ$
3. $\theta > 45^\circ$
4. Not enough information to tell

A cube of side length $a$ is placed in $S$ frame. After correcting for differences in transmission times for light coming from different parts of the cube, what is the volume calculated for the cube in an $S'$ frame that is moving parallel to one side of the cube at a relative speed $0.8c$? ($c$ is the speed of light.)

1. $a^3$
2. $0.6a^3$
3. $0.8a^3$
4. $0.64a^3$

Figure C.34: Waves, Optics, & Modern Physics Clicker Question Sequence C34
One inertial frame $S'$ moves at a velocity $v$ with respect to a second inertial frame $S$, as shown in the sketch below. Uncle Sam is at rest in $S'$ but appears to have a velocity $v$ in $S$, and so has a different momentum $P$ and kinetic energy $K$ in the two frames. This is because:

1. $P$ and $K$ have correct values only in $S$.
2. $P$ and $K$ have correct values only in $S'$.
3. $P$ and $K$ don't have the same values in the two reference frames because of special relativity.
4. $P$ and $K$ don't have the same values in $S$ and $S'$ either with Galilean or special relativity.
5. Relativistic transformations ensure that $P$ and $K$ will be the same in both frames.

Which of the following quantities are the same for Uncle Sam in both reference frames? (K stands for kinetic energy and $p$ stands for momentum).

1. $K^2 - (cp)^2$
2. $\gamma^4 + y^4 + z^4 - (ct)^4$
3. $\gamma \left( mc^2 \right)^2 - (pc)^2$
4. 1 and 3.
5. 2 and 3.
6. 1 and 2.
7. None of the above.
Sam and Sally are stationed at the midpoints of their spaceships. Sally's spaceship is moving at a constant velocity $v$ with respect to Sam's. If Sam receives signals simultaneously from two transmitters at both ends of his spaceship, will Sally also receive these signals simultaneously?

1. Always yes
2. Always no
3. Yes, only if Sally's relative motion is along x direction
4. Yes, only if Sally's relative motion is along y direction

Two stations are far apart. Bill is flying a rocket in the direction from station A to station B. At the instant Bill's rocket is halfway between A and B, both stations launch firecrackers simultaneously. If event A is "firecracker A explodes" and event B is "firecracker B explodes", which event will Bill see first?

1. Event A
2. Event B
3. Bill sees both events at the same instant
4. Cannot be determined

Two stations launch firecrackers. Bill is flying a rocket in the direction from station A to station B. At the instant Bill's rocket passes by station B, he sees firecrackers explode at both stations at the same instant of time. If you are standing at rest in the midpoint between the two stations, which event will you see first?

1. Firecracker at station A
2. Firecracker at station B
3. Both firecrackers A & B at the same time instant
4. Cannot be determined
In a mercury discharge lamp, rays emitted from the cathode strike the glass tube, causing the glass to glow green. These rays, often called cathode rays, are comprised of:

1. Mercury atoms
2. Mercury nucleus
3. Electrons
4. Neutrons
5. Protons
6. Photons

As J. J Thomson observed, when a cathode-ray tube is placed in a magnetic field, cathode rays will be:

1. Deflected upward
2. Deflected downward
3. Deflected into the slide
4. Deflected out of the slide

In Thomson’s cross field experiment (see diagram), a cathode-ray tube with two parallel-plate electrodes is placed in a magnetic field. If the cathode rays are not deflected, the top plate electrode must be:

1. Positive
2. Negative
3. Neutral
4. Cannot be determined

Figure C.37: Waves, Optics, & Modern Physics Clicker Question Sequence C37
The following two curves show the radiation spectra of two objects. Which object is at a higher temperature?

1. Object A
2. Object B
3. Both have the same temperature
4. Cannot be determined

What kinds of spectra do the following graphs correspond to?

Graph A
1. Black body
2. Gas discharge lamp
3. Black body
4. Gas discharge lamp

Graph B
1. Black body
2. Gas discharge lamp
3. Gas discharge lamp
4. Black body

Which of the following pictures corresponds to an absorption spectrum?

A
1. All of the above
2. None of the above

Figure C.38: Waves, Optics, & Modern Physics Clicker Question Sequence C38
A Thomson atom with spread-out charge consists of a spherical "cloud" of positive charge and embedded negative electrons (see diagram). When an alpha particle is shot toward a Thomson atom, which trajectory path does the alpha particle likely follow?

1. 1
2. 2
3. 3
4. 4

Some alpha particles are shot toward the nucleus of a gold atom. Which of the following trajectory paths could the alpha particles take?

1. 1
2. 2
3. 3
4. All of the above

Figure C.39: Waves, Optics, & Modern Physics Clicker Question Sequence C39
The intensity of a beam of light is increased, but the light's frequency is unchanged. Which of the following is true?

1. The photons travel faster.
2. Each photon has more energy.
3. There are more photons per second.
4. The photons are larger.

The following graph shows Millikan's data for determining the threshold frequency for a given material by varying the frequency of the incident light. Which of the following will change the threshold frequency $f_0$?

1. Increase the light intensity.
2. Increase the light frequency.
3. Decrease the light intensity.
4. Decrease the light frequency.
5. Use a different metal.
6. None of the above.

The following graph shows Millikan's data for determining the threshold frequency for a given material by varying the frequency of the incident light. Which of the following will change the slope of the graph?

1. Increase the light intensity.
2. Increase the light frequency.
3. Decrease the light intensity.
4. Decrease the light frequency.
5. Use a different metal.
6. None of the above.
An X-ray photon scattering from an electron at rest is shown on the right. Which of the following correctly describes the energy of the outgoing photon $E_{\text{OUT}}$ as compared to the energy $E_{\text{IN}}$ of the incoming photon?

1. $E_{\text{OUT}} > E_{\text{IN}}$
2. $E_{\text{OUT}} = E_{\text{IN}}$
3. $E_{\text{OUT}} < E_{\text{IN}}$
4. Could be greater sometimes and less others.

(\[ \theta = 180^\circ \] and $\lambda = \frac{4h}{mc}$. What is the wavelength of the scattered X-ray?

$\lambda' = \lambda - \frac{h}{mc}(1 - \cos \theta)$

$h/(mc) = 2.43 \times 10^{-12} \text{ m}$

1. $2.43 \times 10^{-12} \text{ m}$
2. $4.46 \times 10^{-12} \text{ m}$
3. $9.72 \times 10^{-12} \text{ m}$
4. $1.46 \times 10^{-11} \text{ m}$
5. $1.88 \times 10^{-11} \text{ m}$

In the previous question, $\lambda' = 1.46 \times 10^{-11} \text{ m}$. What is the energy of this outgoing photon?

$E_{\gamma} = \frac{hc}{\lambda}$

$h = 4.14 \times 10^{-15} \text{ eV s}$

1. 15 KeV.
2. 25 KeV.
3. 85 KeV.
4. 145 KeV.
5. None of the above.
In the Bohr model of the hydrogen atom only discrete energy levels are possible because:

1. Angular momentum is quantized.
2. Only certain wavelengths can fit in each orbit
3. Bound electrons must have an energy that is negative with respect to unbound electrons.
4. 1 & 2
5. 1 & 3
6. 2 & 3
7. 1 & 2 & 3

This particle is confined in a box. What is its quantum number?
We’ll soon compare this answer to a hydrogen atom.

1. n = 3
2. n = 4
3. n = 5
4. n = 6
5. n = 8

An n = 1 wave function is the lowest wave function that fits smoothly around the orbit. What is the quantum number of this state in a hydrogen atom?

1. 1
2. 2
3. 3
4. 4
5. There’s no way to tell
What is the difference between box and atom cases?

1. The box has only full-wavelength normal modes
2. The atom has both half and full-wavelength normal modes
3. The box has both half and full-wavelength normal modes.
4. There is no difference
5. None of the above

Which of the following pictures resembles orbits for the lowest energy states in the Bohr model?

1. 1
2. 2
3. 3
4. 4
5. None of them.
Lots of light passing through the slit below would result in a diffraction pattern on the screen. Positions B and C mark the first dark fringes of this pattern.

**But, what happens if you shoot just one photon through the slit?**

1. The photon will travel straight and land at position A.
2. There will be a diffraction pattern on the screen but with very low intensity.
3. The photon will land and give a tiny light flash somewhere between B and C.
4. The area between B and C will be bright.

### (b)

Just as a photon passes through the single slit, what is the uncertainty of its position $\Delta x$?

1. L
2. D
3. Width W
4. None of the above

The incoming photon has momentum $p$. When the photon goes through the slit it changes direction. Its transverse momentum, formerly zero, becomes $p \cdot \sin \theta$. **What is the uncertainty of the transverse momentum $\Delta P$ before it makes a light flash on the screen?**

1. $p \cdot \sin \theta$
2. 0
3. $P$
4. Not enough information

---

*Figure C.43: Waves, Optics, & Modern Physics Clicker Question Sequence C43*
What will you get for the product of $\Delta x \Delta p$? Use the de Broglie wave equation $p = \frac{h}{\lambda}$ and the diffraction equation $D \sin(\theta) = \lambda$.

1. Width $w$
2. Wavelength $\lambda$
3. Frequency $f$
4. Planck’s constant $h$
Since particles also have wave aspects, what does this say about our ability to predict particle motion?

1. The better we know where a particle is, the less we know about where it is going.
2. The better we know where a particle is going, the less we know about where it is.
3. We can never perfectly know both where a particle is and where it is going.
4. All of the above.
5. This is garbage, we always can perfectly know where a particle is and where it is going.

Heisenberg’s Uncertainty principle: $\hat{p_x}\hat{x} = \frac{\hbar}{2\pi}$, where $\hbar = 6.63 \times 10^{-34}$ Joule-seconds. Why doesn’t this affect our lives?

1. Our lives are always well determined.
2. This kind of uncertainty only applies to tiny distances.
3. Planck's constant $\hbar$ is really small.
4. How should I know! Don’t bother me with dumb questions.
This is the wave function of a neutron. At what range of $x$ is the neutron most likely to be found?

1. Around $x = x_A$
2. Around $x = x_B$
3. Around $x = x_C$
4. Around $x = 0$
5. Around $x = \infty$

The value of the constant $a$ for the probability density $P(x)$ is:

1. $a = 0.5 \text{ m}^{-1}$
2. $a = 1.0 \text{ m}^{-1}$
3. $a = 1.5 \text{ m}^{-1}$
4. $a = 2.0 \text{ m}^{-1}$
5. $a = 4.0 \text{ m}^{-1}$

Which of the following functions could be a normalized wave function?

1. $\Psi(x) = A\sin x$
2. $\Psi(x) = ax + b$
3. $\Psi(x) = \frac{1}{x}$
4. $\Psi(x) = \ln(x)$
5. $\Psi(x) = Ce^{-x^2/2}$

Figure C.45: Waves, Optics, & Modern Physics Clicker Question Sequence C45
This particle is confined in a box. What is its quantum number?

1. n = 3
2. n = 4
3. n = 5
4. n = 6
5. n = 8

What is the quantum number of this hydrogen atom?

1. n = 1
2. n = 2
3. n = 3
4. n = 4
5. n = 5
6. n = 6

What is the difference between box and atom cases?

1. The box has only full-wavelength normal modes
2. The atom has both half and full-wavelength normal modes
3. The box has both half and full-wavelength normal modes.
4. There is no difference
5. None of the above
If the particle has a mass $m$, what is the corresponding energy of this particle? The DeBroglie wavelength of this particle is $\lambda = \frac{h}{mv}$. ($L$ is the length of the box.)

A. $E = \frac{h^2}{8mL^2}$  
B. $E = \frac{h^2}{4mL^2}$  
C. $E = \frac{h^2}{2mL^2}$  
D. $E = \frac{h^2}{mL^2}$  
E. $E = \frac{2h^2}{mL^2}$

Can you put a particle with mass $m$ and energy $E_1 = \frac{h^2}{4mL^2}$ into the same box with length $L$? How about $E_2 = \frac{2h^2}{mL^2}$?

1. Both can be put in  
2. $E_1$ cannot, $E_2$ can  
3. $E_1$ can, $E_2$ cannot  
4. Both cannot be put in  
5. Cannot be determined

In real life, why can you put golf balls with a continuous range of energies into a hole?

1. Golf balls are large, so Newtonian mechanics applies. Quantum mechanics applies only to submicroscopic particles.  
2. If the mass of the golf ball and the radius of the hole get bigger, the energy difference between acceptable energy levels gets smaller.  
3. Protons and electrons have charges, while a golf ball is neutral. Quantum mechanics doesn’t apply to neutral particles.  
4. The earth’s gravity can pull a massive golf ball into a hole, but submicroscopic masses are less affected by gravity.

Figure C.47: Waves, Optics, & Modern Physics Clicker Question Sequence C47
Figure C.48: Waves, Optics, & Modern Physics Clicker Question Sequence C48
Is the following a possible wave function?

1. Yes
2. No
3. I don’t know

Is the following function a possible wave function for a finite square well?

1. Yes
2. No
3. I do not know

Figure C.49: Waves, Optics, & Modern Physics Clicker Question Sequence C49
The energy difference between the 1st excited state and the ground state is 10.2 eV for hydrogen atom, and 2.1 eV for sodium atom. If a photon of energy 5 eV collide with both atoms, which atom will be excited?

- **Hydrogen**
  - $E_2 = 10.2 \text{ eV}$
  - $E_1 = 0 \text{ eV}$

- **Sodium**
  - $E_2 = 2.1 \text{ eV}$
  - $E_1 = 0 \text{ eV}$

1. Hydrogen atom
2. Sodium atom
3. Neither will be excited
4. Both will be excited to the 1st excited state

An electron collides with a sodium atom, causing it to be excited from its ground state to its first excited. What is the minimum speed of the electron?

- **Sodium**
  - $E_2 = 2.1 \text{ eV}$
  - $E_1 = 0 \text{ eV}$

1. $0.0116 \ c$ (c is the speed of light)
2. $0.0087 \ c$
3. $0.0082 \ c$
4. $0.0029 \ c$
5. $0$

The energy difference between the 1st excited state and the ground state is 10.2 eV for hydrogen atom, and 2.1 eV for sodium atom. If an electron of kinetic energy 5 eV collide with both atoms, which atom will be excited?

- **Hydrogen**
  - $E_2 = 10.2 \text{ eV}$
  - $E_1 = 0 \text{ eV}$

- **Sodium**
  - $E_2 = 2.1 \text{ eV}$
  - $E_1 = 0 \text{ eV}$

1. Hydrogen atom
2. Sodium atom
3. Neither will be excited
4. Both will be excited to the 1st excited state
Out in space where there is no gravity, 2 bar magnets pass into the page through an intense non-uniform magnetic field that points upward and is stronger at the top. What will they do?

1. Both magnets rotate and translate, but 1 moves upward more than 2.
2. Both magnets only rotate.
3. Both magnets rotate and translate, but 2 moves upward more than 1.
4. Both magnets rotate and move upward the same amount.

A beam of silver atoms passes through a non-uniform B-field and strikes a photographic plate, as shown below. Classically, the silver atom is expected to act as if it were a bar magnet with a continuum of orientations. After developing the plate, there will be a black dot where each of the atoms struck. After 100,000 atoms strike the plate, what is the classical prediction for the blackened region?

1. B points upward & gets stronger higher up
2. Two spots, vertical
3. Two spots, horizontal
4. None of the above

A beam of silver atoms passes through a non-uniform B-field and strikes a photographic plate, as shown below. After developing the plate, there will be a black dot where each of the atoms struck. After 100,000 atoms strike the plate, what is the quantum mechanical prediction for the blackened region?

1. B points upward & gets stronger higher up
2. Two spots, vertical
3. Two spots, horizontal
4. None of the above

Figure C.51: Waves, Optics, & Modern Physics Clicker Question Sequence C51
(a) Which nucleus has the largest binding energy per nucleon?

![Average Binding Energy per Nucleon graph]

1. $^4\text{He}$
2. $^{35}\text{Cl}$
3. $^{56}\text{Fe}$
4. $^{116}\text{Sn}$
5. $^{194}\text{Pt}$
6. $^{238}\text{U}$

(b) Which of the following nuclei has the lowest rest mass per nucleon. For $^{35}\text{Cl}$ the number would be $M_{\text{Cl}}/35$.

![Average Binding Energy per Nucleon graph]

1. $^4\text{He}$
2. $^{35}\text{Cl}$
3. $^{56}\text{Fe}$
4. $^{116}\text{Sn}$
5. $^{194}\text{Pt}$
6. $^{238}\text{U}$

(c) Average binding energy per nucleon averages over nuclei near the center that are more tightly bound and nuclei further separated from the center that may be almost unbound. The largest semi-stable nucleus (it has a half life of 3.6 hours) is lawrencium ($^{262}\text{Lr}$). There are no larger nuclei because any additional added nuclei would be unbound. This is because:

1. Coulomb forces are long range and nuclear forces are short range.
2. Coulomb forces are short range and nuclear forces are long range.
3. Both coulomb and nuclear forces are short range.
4. Both coulomb and nuclear forces are long range.
5. None of the above

Figure C.52: Waves, Optics, & Modern Physics Clicker Question Sequence C52
Figure C.52 continued

(d) $^{500}\text{Up}_{113}$ cannot exist because:

1. The neutron's magnetic moments would repel each other.
2. There is no way to fabricate such an unbalanced nucleus.
3. The additional neutrons would have to be stacked into unbound higher energy levels.
4. None of the above.
5. All of the above.
(a) Which of the following processes releases energy?

1. \(^3\text{He} + ^3\text{He} \rightarrow ^4\text{He}\)
2. \(^4\text{Li} + ^8\text{Be} \rightarrow ^8\text{Be}\)
3. \(n + ^{56}\text{Fe} \rightarrow ^{56}\text{Ni} + ^{56}\text{Al} + 2n\)
4. 1 and 2
5. 1 and 3
6. 2 and 3
7. All of them
8. None of them

(b) The final step of hydrogen “burning” in stars consists of combining two \(^3\text{He}\) nuclei to form a stable \(^4\text{He}\) nucleus plus two protons. How much energy is released in this final step? The mass energy of the \(^3\text{He}\) nucleus (without atomic electrons) is 2809.41 MeV, the mass energy of the \(^4\text{He}\) nucleus (without electrons) is 3728.40 MeV and the mass energy of a proton is 938.27 MeV.

\[ ^3\text{He}_2 + ^3\text{He}_2 \rightarrow ^4\text{He}_2 + 2p \]

1. 1.3 MeV
2. 12.9 MeV
3. 130 MeV
4. No energy is released

(c) For the above reaction, assume that each of the deuterium nuclei have the same kinetic energy. What is the approximate kinetic energy they require to overcome coulomb repulsion? The radius of the helium nucleus is 1.55 x 10^{-15} m and the coulomb potential energy for two proton charges is:

\[ U_c = \frac{9 \times 10^9 \text{J} - m \cdot c^2}{r} \left(1.6 \times 10^{-19} \text{c}^2\right)^2 \]

1 MeV = 1.60 x 10^{-12} J

1. 0 MeV
2. 0.10 MeV
3. 0.93 MeV
4. 9.30 MeV
5. None of the above

Figure C.53: Waves, Optics, & Modern Physics Clicker Question Sequence C53
Which of the following two nuclear potential wells is for a neutron and which for a proton?

1. A A
2. A B
3. B A
4. B B

The positive “lip” on the right-hand potential is due to the fact that:

1. The shape of the nuclear force is different for a neutron and a proton.
2. Occurs only for the shell model of the nucleus.
3. Like charges repel.
4. All of the above.
5. None of the above.

The shape of the potentials below indicate that nuclear reactions can only occur if:

1. Protons have sufficiently high energy.
2. Neutrons have sufficiently high energy.
3. Neutrons and protons both have sufficiently high energy.
4. None of the above.
5. All of the above.
Which of the following energy levels would be required in a nucleus with a long half life that is unstable to alpha decay?

1. $E_A$
2. $E_B$
3. $E_C$
4. $E_D$
5. $E_E$
6. $E_F$
Scattering experiments have determined that stable nuclei have radii that are proportional to the cube root of the atomic number: \( r = r_0 A^{1/3} \) where \( r_0 = 1.2 \times 10^{-15} \) meters.

This formula can only be true if:

1. Nucleons have widely spaced orbits as for the Bohr model of the atom.
2. The neutron excess isn’t too great.
3. The center-to-center distance between neighboring nucleons is approximately one nucleon diameter...
4. None of the above.

The radius of a nucleus typically is how much smaller than that of the atom that it is in?

\[
\frac{r_{\text{NUCLEUS}}}{r_{\text{ATOM}}}
\]

1. \( 10^{-9} \)
2. \( 10^{-7} \)
3. \( 10^{-5} \)
4. \( 10^{-3} \)
5. \( 10^{-1} \)
6. They’re the same size.

The DeBroglie wavelength of a particle is

\[
\lambda = \left( \frac{\hbar}{p} \right) \approx \left( \frac{\hbar c}{E} \right) \approx \left( \frac{2 \times 10^{-11} \text{ MeV meters}}{E \text{ (in MeV)}} \right)
\]

for particles whose total energy is much greater than their rest mass. What is the lowest total energy electron that you would use to investigate the shape of a nucleus?

1. 1 MeV.
2. 10 MeV.
3. 100 MeV.
4. 1000 MeV.
5. 10,000 MeV.

Figure C.55: Waves, Optics, & Modern Physics Clicker Question Sequence C55
Which type of nuclear decay would give rise to exponential loss of the original nuclei?

1. Alpha decay (emission of an alpha particle).
2. Beta decay (emission of a positron or electron plus a neutrino).
3. Both of the above.
4. Neither of the above.

Three lifetimes have passed. What fraction of the original nuclei have are left undecayed?

1. 0.250
2. 0.135
3. 0.125
4. 0.062
5. 0.050
6. None of the above.

A rock contains twice as much stable $^{40}$Ar as radioactive $^{40}$K. $^{40}$K decays into $^{40}$Ar with a lifetime (not half life) of $1.80 \times 10^9$ years. At zero lifetime there was no $^{40}$Ar. How old is the rock?

1. $1.98 \times 10^9$ years.
2. $2.5 \times 10^9$ years.
3. $3.96 \times 10^9$ years.
4. $5.00 \times 10^9$ years.
5. None of the above.
Adding one neutron to $^{235}\text{U}$ results in the excited state $^{236}\text{U}^*$ that quickly decays into unstable isotopes of xenon and strontium plus two extra neutrons.

$$^{235}\text{U}_{92} + n \rightarrow ^{236}\text{U}_{92} \rightarrow ^{140}\text{Xe}_{54} + ^{94}\text{Sr}_{38} + 2n$$

This process is known as:

1. Neutron decay.
2. Fusion.
3. Fission.
4. None of the above.

Adding one neutron to $^{235}\text{U}$ results in the excited state $^{236}\text{U}$ that quickly decays into unstable isotopes of xenon and strontium plus two extra neutrons. This process is modeled by a liquid drop nuclear model. Which of the two steps on the right is not included in this model?

1. 1.
2. 2.
3. Both of them are included
4. Neither is included.

Adding one neutron to $^{236}\text{U}_{92}$ results in the excited state $^{236}\text{U}$ that quickly fissions into unstable isotopes of xenon and strontium plus two extra neutrons.

Comparing the sum of the rest masses in initial and final states, you determine that:

1. Sum of masses of $(^{235}\text{U} + n)$ > Sum of masses of $(^{140}\text{Xe} + ^{94}\text{Sr} + 2n)$
2. Sum of masses of $(^{140}\text{Xe} + ^{94}\text{Sr} + 2n)$ > Sum of masses of $(^{235}\text{U} + n)$
3. Sum of masses of $(^{140}\text{Xe} + ^{94}\text{Sr} + 2n)$ > Sum of masses of $(^{238}\text{U} + n)$

Figure C.57: Waves, Optics, & Modern Physics Clicker Question Sequence C57
Adding one neutron to $^{235}$U results in the excited state $^{236}$U that quickly decays into unstable isotopes of xenon and strontium plus two extra neutrons. How much energy is released in the process? The binding energy/nucleon of the three participating nuclei are given below.

<table>
<thead>
<tr>
<th>Nucleus</th>
<th>$\sim$ B.E./nucleon</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{235}$U$_{92}$</td>
<td>7.6 Mev / nucleon</td>
</tr>
<tr>
<td>$^{136}$Xe$_{54}$</td>
<td>8.5 Mev / nucleon</td>
</tr>
<tr>
<td>$^{90}$Sr$_{38}$</td>
<td>8.6 Mev / nucleon</td>
</tr>
</tbody>
</table>

1. 212 MeV  
2. 21 MeV  
3. 2120 MeV  
4. None of the above
APPENDIX D
POSTTEST QUESTIONS #33 – 36
FOR
2007 SPRING E&M
33. A charged particle is placed in a magnetic field, as shown below. The particle is given an initial velocity \( \mathbf{v} \) in the direction indicated by the large arrow. Circle the direction of the force experienced by the charged particle. Ignore gravity.

In the following 3 problems, all bulbs have the same resistance \( R \), and all batteries are 12 volts with zero internal resistance.

34. What happens to the brightness of bulbs A and B when the switch is closed?
   a. A stays the same and B dims.
   b. A gets brighter and B dims.
   c. A and B both get brighter.
   d. A and B both get dimmer.
   e. A and B both remain the same.

35. Given that the battery is 12 volts and all the bulbs have the same resistance \( R \), what is the voltage difference \( (V_A - V_B) \) between the points shown by the black dots?
   a. 4 V.
   b. 6 V.
   c. 8 V.
   d. 10 V.
   e. 12 V.

36. Which of the following bulbs, A, B, or C, has more energy delivered to it per second?
   a. A.
   b. B.
   c. C.
   d. B=C
   e. A=B=C.
APPENDIX E

PRETEST QUESTIONS #27 – 34

FOR

2007 FALL MECHANICS
The following two questions refer to collisions between a car and trucks. For each description of a collision below, choose the one answer from the possibilities A through J that best describes the forces between the car and the truck.

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 is in the way of the truck.
D. The truck exerts a force on the car but the car doesn't 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.
F. Not enough information is given to pick one of the answers above.
J. None of the answers above describes the situation correctly.

27. They are both moving at the same speed when they collide. Which choice describes the forces? (In this question the truck is much heavier than the car.)

28. The truck is standing still when the car hits it. Which choice describes the forces? (In this question the truck is a small pickup and is the same weight as the car.)
29. A small metal ball with speed 10 m/s enters a box (without spinning) along a direction depicted in the diagram. Some time later the metal ball is observed leaving the box with the same speed 10 m/s (without spinning) but different direction as shown.

From this, we can conclude that in the box:

(a) The net force on the metal ball was nonzero, and the net work done on the metal ball was nonzero
(b) The net force on the electron was nonzero, but the net work done on the electron was zero
(c) The net force on the electron was zero, but the net work done on the electron was nonzero
(d) The net force on the electron was zero, and the net work done on the electron was zero
(e) Not enough information to determine

30. Two identical stones, A and B, are shot from a cliff from the same height and with identical initial speeds $v_0$. Stone A is shot vertically up, and stone B is shot vertically down (see diagram). Which one of the following statements best describes which stone has a larger speed right before it hits the ground?

(a) Both stones have the same speed.
(b) A, because it travels a longer path.
(c) A, because it takes a longer time.
(d) A, because it travels a longer path and takes a longer time.
(e) B, because no work is done against the gravitational force.
31. Two identical bullets are fired horizontally with identical speed \( v_0 \) at two blocks of equal mass. The blocks rest on a frictionless horizontal surface and are made of hard steel and soft wood respectively (see diagram). One bullet bounces elastically off the steel block (with no mechanical energy dissipated). The other bullet becomes embedded inside the wood block. Which one of the following statements best describes which block travels faster after the collision?

(a) The wood block, because it has gained the momentum of the bullet, while the other bullet does not impart its momentum to the steel block.
(b) The wood block, because the bullet transfers all of its kinetic energy to it.
(c) The wood block, because its larger effective mass after the collision, in accordance with Newton's second law, results in a larger force to accelerate the block.
(d) The steel block, because the bullet bounces off from it.
(e) Both blocks travel with the same speed.

32. A fat beetle walks rapidly inward on top of a disk that is freely rotating about the axle at \( P \). Consider the system consists of the beetle plus the disk. While the beetle moves inward, the

(a) The magnitude of the system’s angular momentum decreases.
(b) The magnitude of the system’s angular momentum increases.
(c) The magnitude of the system’s angular velocity decreases.
(d) The magnitude of the system’s angular velocity increases.
(e) Nothing changes.
33. Joe and David, who have the same mass, are standing still on a merry-go-around that can freely rotate around its axial with negligible friction. Initially the merry-go-around does not rotate. Then Joe starts walking slowly along a clockwise circle (from top view) at a constant speed 0.2 m/s, and David starts walking slowly along a different counterclockwise circle (from top view) at the same constant speed 0.2 m/s. Both Joe’s circle and David’s circle share the same center as the merry-go-around, but have different radius. If you observe from top, you will find the merry-go-around

(a) is rotating clockwise at a constant speed
(b) is rotating clockwise at a changing speed
(c) is rotating counterclockwise at a constant speed
(d) is rotating counterclockwise at a changing speed
(e) does not rotate

34. Four identical (low-mass) disks, each of which can rotate freely around its fixed axle at center with negligible friction, have some heavy metal pieces glued on their surfaces. The metal pieces on each disk have the same mass but different shape. Initially all the disks are rotating at a constant rate of 10 resolutions per second. Then you apply a constant force on the edge of each disk by bringing a rough surface to its rim. If the force applied on each disk is the same, which disk will take the longest time to stop?

A B D C

Rough Surface Rough Surface Rough Surface Rough Surface

10 res/second 10 res/second 10 res/second 10 res/second

Force Force Force Force
APPENDIX F

PRETEST

FOR

2008 SPRING WAVES, OPTICS, & MODERN PHYSICS
1. The following graph shows the displacement ($x$) vs. time ($t$) of a simple harmonic oscillator moving along the $x$ axis. There are five dots on the curve, each of which indicates a time instant. At which time instant does the oscillator experience a force to the positive $x$ direction but have zero velocity?

(A) Point A  (B) Point B  (C) Point C  (D) Point D  (E) Point E

2. At $t = 0$, an oscillator is started with a velocity $\vec{v}$ to the left at the position shown below. The equation of harmonic oscillation is: $x = A\cos(\omega t + \phi)$, where $A$ is 100. What is the possible value of $\phi$?

(A) $-\frac{\pi}{3}$  (B) 0  (C) $\frac{\pi}{3}$  (D) $\frac{\pi}{2}$  (E) $\frac{2\pi}{3}$
3. A transverse wave is traveling to the right with velocity 2m/s and wave length 4m. The graph on the top describes the time history of how the particle at \(x = +1\)m vibrates. Select the correct snapshot for all \(x\) positions of the wave at \(t = +0.5\) second.
4. Two identical waves travel to the left, as shown in the top sketch. Wave 1 reflects off the end and then travels to the right. Wave 2 is still traveling to the left and has not yet reflected. Which of the following wire shapes could occur as the waves pass through one another?

(A) Diagram (1)
(B) Diagram (2)
(C) Diagram (3)
(D) Diagram (4)
(E) Diagrams (1) and (2)
(F) Diagrams (1) and (3)
(G) Diagrams (1) and (4)
(H) Diagrams (2) and (3)
(I) Diagrams (2) and (4)
(J) Diagrams (3) and (4)
5. Two point sources, S and P, are in phase and emit identical sound waves of wavelength $\lambda$. What type of interference occurs at C and D?

![Diagram of two point sources and positions C and D]

<table>
<thead>
<tr>
<th>Type of Interference at C</th>
<th>Type of Interference at D</th>
</tr>
</thead>
<tbody>
<tr>
<td>(A) Fully constructive</td>
<td>Fully constructive</td>
</tr>
<tr>
<td>(B) Fully constructive</td>
<td>Fully destructive</td>
</tr>
<tr>
<td>(C) Fully destructive</td>
<td>Fully constructive</td>
</tr>
<tr>
<td>(D) Fully destructive</td>
<td>Fully destructive</td>
</tr>
<tr>
<td>(E) Fully constructive</td>
<td>Depends on the distance between C &amp; D</td>
</tr>
<tr>
<td>(F) Fully destructive</td>
<td>Depends on the distance between C &amp; D</td>
</tr>
<tr>
<td>(G) Depends on $\lambda$</td>
<td>Depends on $\lambda$</td>
</tr>
</tbody>
</table>

6. A guitar string 0.4m long and fixed at both ends oscillates in its $n = 3$ mode. The speed of waves on the guitar string is 300 m/s. What is the frequency of the emitted wound wave?

(A) 300 Hz  
(B) 450 Hz  
(C) 900 Hz  
(D) 1200 Hz  
(E) 1125 Hz
7. A coin is placed at the bottom of a water tank. If a person looks at the coin from outside of the water tank, he sees the coin is:

(A) at a greater depth than it really is
(B) at the same depth as it really is
(C) at a smaller depth than it really is
(D) Cannot be determined.

8. A high frequency electromagnetic wave is propagating toward the +x direction. Its electric field \( \vec{E} \) is oscillating parallel to the \( y \) axis, and its magnetic field \( \vec{B} \) is oscillating parallel to the \( z \) axis. A straight conducting wire is oriented in three different positions: parallel to the \( x \) axis, parallel to the \( y \) axis and parallel to the \( z \) axis. In which orientation, will there be current flow in the wire?

(A) Wire parallel to the \( x \) axis
(B) Wire parallel to the \( y \) axis
(C) Wire parallel to the \( z \) axis
(D) There is current in the wire for all three orientations
(E) There is no current in the wire for any orientation
You use monochromatic wavelength of 600 nm to produce double-slit interference pattern on a screen. Initially at the central location of the screen there is a bright fringe. Now you submerge the entire experiment setup into water (n = 1.3), and still use wavelength of 600 nm.

9. What do you see at the central location of the screen?
(A) Bright fringe
(B) Dark fringe
(C) Between bright and dark
(D) Depends on the separation of the two slits
(E) None of the above is correct

10. How does the separation of the bright fringes on the screen change?
(A) The separation is increased
(B) The separation is decreased
(C) The separation stays the same
(D) It depends on the separation of the two slits
(E) None of the above is correct
11. If monochromatic light of wavelength $\lambda$ is diffracted through a single slit of width $w$, the width of the central bright fringe is $L$, as shown below. If the wavelength is changed to $2\lambda$ and the slit width to $2w$, what would be the new width of the central bright fringe?

(A) $L$
(B) $2L$
(C) $4L$
(D) $\frac{1}{2} L$
(E) $\frac{1}{4} L$
(F) None of the above
12. In S frame three meter sticks are placed parallel to the $x$, $y$ and $z$ axes respectively. Another frame $S'$ is moving away from S frame with a relative velocity that is parallel to the $x$ axis. If you observe the three meter sticks from the $S'$ frame, which meter stick(s) will become shorter from your perspective?

(A) Meter-stick parallel to the $x$ axis  
(B) Meter-stick parallel to the $y$ axis  
(C) Meter-stick parallel to the $z$ axis  
(D) None of them  
(E) All of them
13. Wendy is sitting in the middle of a barn equidistant between two superfast doors, as shown in the sketch. Mike is sitting at the wheel of a car moving at 75% of the speed of light. Wendy sees a Lorentz-contracted car and simultaneously closes and then opens the doors, for an instant trapping the car inside. Wendy then radios Mike, who says there is no way that his monster car could have been trapped inside such a puny Lorentz-contracted barn. So who is right?

(A) Mike is right, because to him his car didn’t fit inside
(B) Wendy is right because she saw Mike’s car fit inside
(C) Both are correct
(D) Neither is correct
14. Lots of photons passing through the slit below would result in a diffraction pattern on an infinitely large screen. Positions A and E mark the first dark fringes of this pattern.

If you shoot just two photons through the slit what would happen?

(A) Both photons will travel straight and must land at position C.
(B) There will be a diffraction pattern on the screen but with very low density.
(C) Both photons will hit the screen, and a tiny light flash is somewhere on the screen.
(D) All area between A and E will be bright.
(E) The screen will remain dark.
15. Which of the following is the correct energy level diagram for the hydrogen atom?

(A) Diagram A
(B) Diagram B
(C) Diagram C
(D) Diagram D
(E) Diagram E
16. When a beam of infrared light (with a wavelength $\lambda$ and intensity $I$) is shined perpendicularly onto a clean metal surface for 10 seconds, no electron is ejected from the metal surface. Which of the following can you change so that an electron is ejected from the metal surface?

(A) Shine the beam for longer time.
(B) Increase the intensity of the light.
(C) Increase the wavelength of the light.
(D) Change the angle of incidence of the light.
(E) None of the above

17. You have three electrons A, B and C with energy values $E_A = \frac{h^2}{8mL^2}$, $E_B = \frac{h^2}{2mL^2}$, and $E_C = \frac{2h^2}{mL^2}$ respectively. Which electron(s) can you confine into a tube with length $L$?

(A) Electron A
(B) Electron B
(C) Electron C
(D) None of them
(E) All of them
18. Assume that an alpha particle exists inside a nucleus. Which of the following states and associated potential wells could account for a nucleus that decays by emission of an alpha particle?

(A) $E_1$
(B) $E_2$
(C) $E_3$
(D) All of the above states
(E) None of the above states
19. Using the above graph of binding energy per nucleon versus atomic number, estimate which of the following elements is the **most massive** stable nucleus that could be constructed by fusion of lighter nuclei serving as fuel in burning stars? Remember that when something burns, it releases energy.

(A) He\(^4\)
(B) Cl\(^{35}\)
(C) Fe\(^{56}\)
(D) Sn\(^{116}\)
(E) Pt\(^{194}\)
(F) U\(^{238}\)
(G) Cannot tell from the above graph.
APPENDIX G

PRETEST

FOR

2008 FALL MECHANICS
Questions 1 and 2 refer to collisions between a car and a truck. For each description of a collision below, choose one answer from the possibilities A through G that best describes the forces between the car and the truck.

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 is in the way of the truck.
D. The truck exerts a force on the car but the car doesn't 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.
F. Not enough information is given to pick one of the answers above.
G. None of the answers above describes the situation correctly.

1. The car and truck are both moving at the same speed when they collide. Which choice describes the forces? *(In this question the truck is much heavier than the car.)*

2. The truck is standing still when the car hits it. Which choice describes the forces? *(In this question the truck is a small pickup and has the same weight as the car.)*
3. A small metal ball with speed 10 m/s enters a box (without spinning) along a direction depicted in the diagram. Some time later the metal ball is observed leaving the box with the same speed 10 m/s (without spinning) but different direction as shown.

![Diagram of box with directions for enter and exit](image)

From this, we can conclude that in the box:

a. The net force on the ball was nonzero and the net work done on the ball was nonzero
b. The net force on the ball was nonzero but the net work done on the ball was zero
c. The net force on the ball was zero but the net work done on the ball was nonzero
d. The net force on the ball was zero and the net work done on the ball was zero
e. Not enough information to determine

4. Two identical stones, A and B, are shot from a cliff from the same height and with identical initial speeds v₀. Stone A is shot vertically up, and stone B is shot vertically down (see diagram). Which one of the following statements best describes which stone has a larger speed right before it hits the ground?

![Diagram of stones](image)

a. Both stones have the same speed.
b. A, because it travels a longer path.
c. A, because it takes a longer time.
d. A, because it travels a longer path and takes a longer time.
e. B, because no work is done against the gravitational force.

5. Two identical bullets are fired horizontally with identical speed v₀ at two equal mass blocks. The blocks rest on a frictionless horizontal surface; one is made of hard steel and the other of soft wood. One bullet bounces elastically off the steel block (no mechanical energy dissipated). The other bullet becomes embedded inside the wood block. Which block travels faster after the collision?

![Diagram of bullet collision](image)

a. The wood block, because it has gained the momentum of the bullet.
b. The wood block, because it has gained all of the kinetic energy of the bullet.
c. The wood block, because its larger effective mass after the collision results in a larger force of acceleration.
d. The steel block, because the bullet bounces from it.
e. Both blocks travel with the same speed.
6. A fat beetle walks rapidly inward on top of a disk that is freely rotating about the axle at P. Consider the system consisting of the beetle plus the disk. While the beetle moves inward, which of the following statements is correct?

a. The magnitude of the system’s angular momentum decreases.
b. The magnitude of the system’s angular momentum increases.
c. The magnitude of the system’s angular velocity decreases.
d. The magnitude of the system’s angular velocity increases.
e. Nothing changes.

7. A block slides on a frictionless ramp, as shown below. At which of the positions does the block experience zero net acceleration?

a. A
b. B
c. C
d. D
e. None of them

8. A person pulls a block across a rough horizontal surface at a constant speed by applying a force F. The arrows in the sketch indicate the directions, but not necessarily the magnitudes of the forces on the block. Which of the following relations among the force magnitudes W, k, N and F must be true?

a. F=k and N=W
b. F=k and N=W
c. F>k and N<W
d. F>k and N=W
e. None of the above choices.
The sketch used for the questions 9 and 10 depicts two pucks on a frictionless table. Puck II is four times as massive as puck I. Starting from rest, the pucks are pushed across the table by two equal forces.

9. Which puck will have the greater kinetic energy upon reaching the finish line?

a. I  
b. II  
c. They both have the same kinetic energy  
d. Too little information to answer

10. Which puck will have the greater momentum upon reaching the finish line?

a. I  
b. II  
c. They both have the same momentum  
d. Too little information to answer

This discussion and associated figure relates to questions 12 and 13. A frictionless channel in the shape of a segment of a circle with center at O has been anchored to a frictionless horizontal table top. The sketch is made 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.

11. All forces on the ball are summed just as it reaches a position at the origin of all of the arrows. Select the arrow that best represents the resulting net force on the ball.

a. 1  
b. 2  
c. 3  
d. 4  
e. 5  
f. 6  
g. 7  
h. 8

12. Which path would the ball most closely follow after it exits the channel at R and moves across the frictionless horizontal table top?

a. A  
b. B  
c. C  
d. D  
e. E  
f. F
13. 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.

Which of the paths shown below best represents the path of the rocket between points “b” and “c”?

a. (A)  
b. (B)  
c. (C)  
d. (D)  
e. (E)

14. Which graph of distance versus time corresponds to the graph of acceleration versus time shown on the right?

15. The figure shows a block attached to a spring. The natural length of the spring is when the block is at position O. We push the block so that it moves to position X. When we let it go it accelerates toward position O, eventually reaching position Y where it momentarily stops. As the spring pushed the block from X to O it did work +W on the block. What is the work that the spring does on the block as the block moves from X to Y?

a. Less than or equal to -4W  
b. -2W  
c. -W  
d. 0  
e. +W  
f. +2W  
g. Greater than or equal to +4W
The following discussion relates to questions 18 and 19. Strings are wound around two pucks that have identical size and mass. One string is around the outer rim of puck 1, and the other is around the axle of puck 2. You pull both pucks from rest at the same time by using the same force $F$. Both pucks initially start at rest, and move on a frictionless surface.

16. Which puck undergoes the greater linear acceleration?
   
   a. Puck 1  
   b. Puck two  
   c. The linear accelerations are the same.  
   d. It depends on the magnitude of the force.

17. The two pucks eventually cross the finish line. As they cross, on which puck have you done more work?
   
   a. Puck 1  
   b. Puck 2  
   c. The work done is the same  
   d. It depends on the difference in time for the pucks to reach the finish line.

18. An elevator is being lifted up an elevator shaft at a constant speed by a steel cable as shown in the figure. 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. they depend on how fast the elevator is moving.  
   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).


Stephen L. Lesniak, “Active learning and other teaching activities as perceived by part-time faculty and students in a professional degree program designed for adult learners,” (Doctoral dissertation, University of La Verne, 1995).


Melvin L. Silberman, Active Learning: 101 Strategies to Teach Any Subject, (Allyn and Bacon, Boston, 1996).


